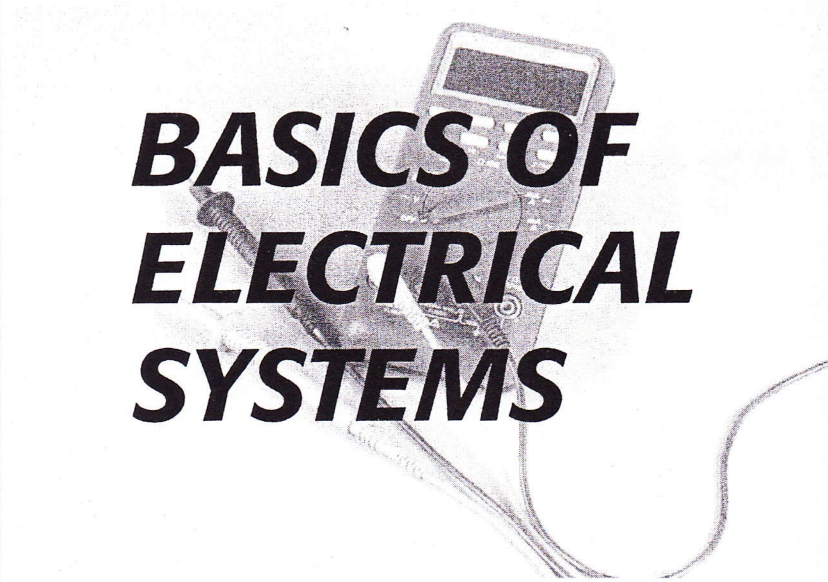
Basics of Electrical Systems

BASICS OF ELECTRICAL SYSTEMS



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OBJECTIVES

◆ ***Define the terms normally used to describe electricity.*** ◆ ***Use Ohm's law to determine voltage, current, and resistance.*** ◆ ***List the basic types of electrical circuits.*** ◆ ***Describe the differences between a series and a parallel circuit.*** ◆ ***Name the various electrical components and their uses in electrical circuits.*** ◆ ***Describe the different kinds of automotive wiring.*** ◆ ***Read electrical automotive diagrams.*** ◆ ***Describe how each of the major types of electrical test equipment are connected and interpreted.*** ◆ ***Perform troubleshooting procedures using meters, testlights, and jumper wires.*** ◆ ***Explain the principles of magnetism and electromagnetism.***

Understanding electrical components and their operation is absolutely essential to properly servicing today's cars and trucks. Although some electrical basics were presented in an earlier chapter, these will be repeated and expanded upon. Repeating some of these facts emphasizes the importance of this knowledge.

BASICS OF ELECTRICITY

Perhaps the one reason why some people find it difficult to understand electricity is that they cannot see it. By actually knowing what it is and what it is *not*, you can easily understand it. Electricity is not magic! It is something that takes place or can take place in everything you know. It not only provides power for lights, TVs, stereos, and refrigerators, it is also the basis for the communications between our brain and the rest of our bodies. Although electricity cannot be seen, the effects of it can be seen, felt, heard, and smelled. One of the most common displays of electricity is a lightning bolt. Lightning is electricity, a large amount of electricity. The power of lightning is incredible. Using the power from much smaller amounts of electricity to perform some work is the basis for an automobile's electrical system. Electricity cannot be seen because it results from the movement of extremely small objects that move at the speed of light (669,600,000 miles per hour).

Flow of Electricity

All things are made up of atoms (Figure 14–1), which are extremely small particles. In the center of every atom is a nucleus. The nucleus contains positively charged particles called protons and particles called neutrons that have no charge. Negatively charged particles called electrons orbit around every nucleus. The electrons stay in orbit around the nucleus because they are naturally attracted to the protons. Every type of atom has a different number of protons and electrons, but the number of protons and electrons in each atom is equal. Therefore, the total electrical charge of an atom is zero, or neutral.

Electricity is the flow of electrons from one atom to another (Figure 14–2). The release of energy as one electron leaves the orbit of one atom and jumps into the orbit of another is electrical energy. The key

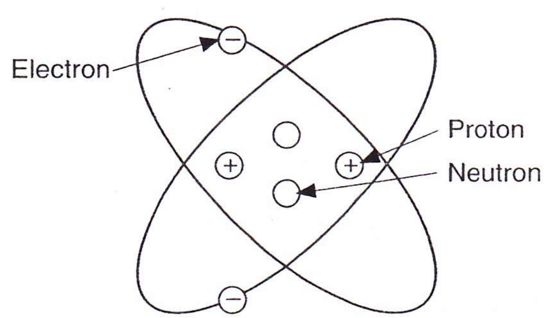


FIGURE 14–1 Basic structure of an atom.

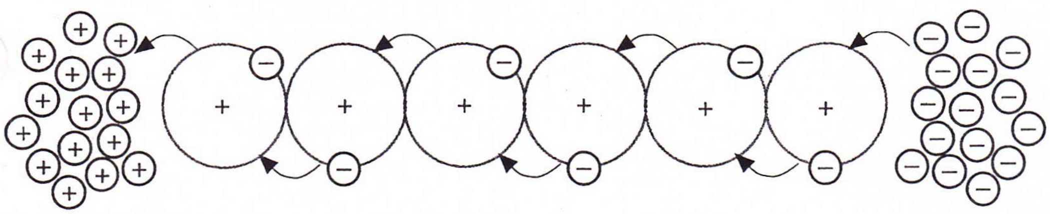


FIGURE 14–2 Electricity is the flow of electrons from one atom to another.

to creating electricity is to provide a reason for the electrons to move to another atom.

There is a natural attraction of electrons to protons. Electrons have a negative charge and are attracted to something with a positive charge. When an electron leaves the orbit of an atom, the atom then has a positive charge. An electron moves from one atom to another because the atom next to it appears to be more positive than the one it is orbiting around.

An electrical power source provides for a more positive charge and to allow for a continuous flow of electricity, it supplies free electrons. To have a continuous flow of electricity, three things must be present: an excess of electrons in one place, a lack of electrons in another place, and a path between the two places.

Two power or energy sources are used in an automobile's electrical system. These are based on a chemical reaction and magnetism. A car's battery is a source of chemical energy. A chemical reaction in the battery provides for an excess of electrons and a lack of electrons in another place. Batteries have two terminals, a positive and a negative. Basically, the negative terminal is the outlet for the electrons and the positive terminal is the inlet for the electrons to get to the protons. The chemical reaction in a battery causes a lack of electrons at the positive (+) terminal and an excess at the negative (–) terminal. This creates an electrical imbalance, causing the electrons to flow through the path provided by a wire.

The chemical process in the battery continues to provide electrons until the chemicals become weak. At that time, either the battery has run out of electrons or all the protons are matched with an electron. When this happens, there is no longer a reason for the electrons to want to move to the positive side of the battery. To the electrons, it no longer looks more positive. Fortunately, the vehicle's charging system restores the battery's supply of electrons. This allows the chemical reaction in the battery to continue indefinitely. In an electrical diagram, a battery is drawn as shown in Figure 14–3.

Electricity and magnetism are interrelated. One can be used to produce the other. Moving a wire (a conductor) through an already existing magnetic field (such as a permanent magnet) can produce electricity. This process of producing electricity through magnetism is called induction. In a generator, a coil of wire is moved through a magnetic field. In an alternator, a magnetic field is moved through a coil of wire. In both cases, electricity is produced. The amount of electricity produced depends on a number of factors, including the strength of the magnetic field, the number of wires that pass through the field, and the speed at which the wire moves through the magnetic field.

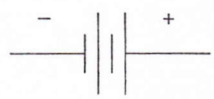


FIGURE 14–3 Symbol for a battery.

ELECTRICAL TERMS

Electrical current describes the movement or flow of electricity. The greater the number of electrons flowing past a given point in a given amount of time, the more current the circuit has. The unit for measuring electrical current is the ampere, usually called an amp. The instrument used to measure electrical current flow in a circuit is called an ammeter.

In the flow of electricity, millions of electrons are moving past any given point at the speed of light. The electrical charge of any one electron is extremely small. It takes millions of electrons to make a charge that can be measured. For these reasons, 1 ampere of current means that 6.28 billion billion electrons are flowing past a given point in 1 second.

There are two types of current: direct current (DC) and alternating current (AC). In direct current, the electrons flow in one direction only. In alternating current, the electrons change direction at a fixed rate. Typically, an automobile uses DC while the current in homes and buildings is AC. Some components of the automobile generate or use AC. These will be discussed in later chapters.

Although there are many theories about current and the direction in which it flows, it is correct to base your understanding on current flowing from a

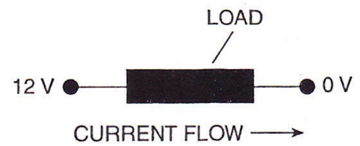


FIGURE 14–4 Current moves from a point of higher potential to a point of lower potential.

Ω

FIGURE 14–5 Common symbol for an ohm.

point of positive voltage to a point of less positive, or negative, voltage (Figure 14–4).

Voltage is electrical pressure. It is the force developed by the attraction of the electrons to protons. The more positive one side of the circuit is, the more voltage is present in the circuit. Voltage does not flow; it is the pressure that causes current flow. To have current flow, some force is needed to move the electrons between atoms. This force is the pressure that exists between a positive and negative point within an electrical circuit. This force, also called electromotive force (EMF), is measured in units called volts. One volt is the amount of pressure required to move 1 ampere of current through a resistance of 1 ohm. Voltage is measured by an instrument called a voltmeter.

When any substance flows, it meets resistance. The resistance to electrical flow can be measured. The resistance to current flow produces heat. This heat can be measured to determine the amount of resistance. A unit of measured resistance is called an ohm. The common symbol for an ohm is shown in Figure 14–5. Resistance can be measured by an instrument called an ohmmeter. Differing amounts of resistance are measured by changing scales (such as × 1, × 10, × 100) on the ohmmeter.

Circuit Terminology

An electrical circuit is considered complete when there is a path that connects the positive and negative terminals of the electrical power source. A completed circuit is called a **closed circuit**, whereas an incomplete circuit is called an **open circuit**. When a circuit is complete, it is said to have **continuity**. Conductors are drawn in electrical diagrams as a line connecting two points, as shown in Figure 14–6.

Most automotive electrical circuits use the chassis as the path from the negative side of the battery.

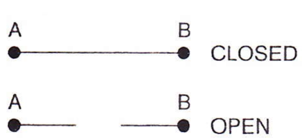


FIGURE 14–6 Conductors are drawn as lines from one point to another.

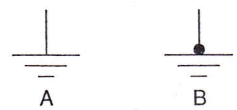


FIGURE 14–7 Symbols for grounds: (A) made through the component's mounting; (B) made by a remote wire.

Electrical components have a lead that connects them to the chassis. These are called the chassis ground connections. These connections can be made through a wire or through the mounting of the component. Chassis ground connections are drawn to show which type of connection is normal for that part (Figure 14–7). When the ground is made through the mounting of the component, the connection is represented with the drawing A. When the ground is made by a wire that connects to the chassis, the connection is shown as B.

In a complete circuit, the flow of electricity can be controlled and applied to do useful work, such as light a headlamp or turn over a starter motor. Components that use electrical power put a load on the circuit and consume electrical energy. These components are often referred to as electrical loads. Loads are drawn in electrical diagrams as a symbol representing the part or as a resistor. The typical drawing of a resistor is shown in Figure 14–8.

The amount of current that flows in a circuit is determined by the resistance in that circuit. As resistance goes up, the current goes down. The total resistance in a circuit determines how much current will flow through the circuit. The energy used by a load is measured in volts. Amperage stays constant in a circuit but the voltage is dropped as it powers a load. Measuring voltage drop tells how much energy is being consumed by the load.

Ohm's Law

Hundreds of years ago, a scientist studied electricity and the interrelationship of the key elements of electricity. He found it takes one volt of electrical pressure to push one ampere of electrical current through one ohm of resistance. This statement is the basic law of electricity. It is known as **Ohm's law**.

A simple electrical circuit is a load connected to a voltage source by conductors. The resistor could be a fog light, the voltage source could be a battery, and the conductor could be a copper wire (Figure 14–9).

In any electrical circuit, current (I), resistance (R), and voltage (E) work together in a mathematical relationship. This relationship is expressed in a mathematical statement of Ohm's law. Ohm's law can be applied to the entire circuit or to any part of a circuit.

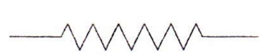


FIGURE 14–8 Symbol for a resistor.

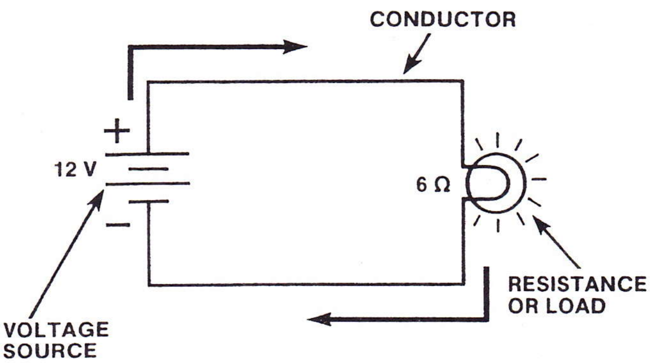


FIGURE 14–9 A simple circuit consists of a voltage source, conductors, and a resistance or load.

When any two factors are known, the third factor can be found by using Ohm's law. Using the circle shown in Figure 14–10, you can easily find the formula for calculating the unknown element. By covering the element you need to find, the necessary formula is shown in the circle.

To find voltage, cover the *E* (Figure 14–11). The voltage (E) in a circuit is equal to the current (I) in amperes multiplied by the resistance (R) in ohms.

To find current, cover the *I* (Figure 14–12). The current (amperage) in a circuit equals the voltage divided by the resistance (in ohms).

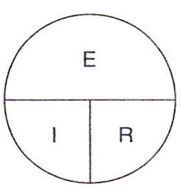


FIGURE 14–10 Ohm's law.

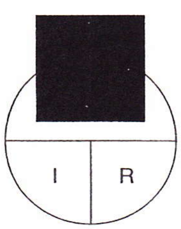


FIGURE 14–11 To find voltage, cover the *E* and use the exposed formula.

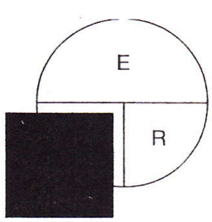


FIGURE 14–12 To find current, cover the *I* and use the exposed formula.

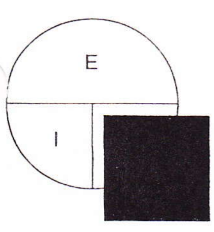


FIGURE 14–13 To find resistance, cover the *R* and use the exposed formula.

To find resistance, cover the *R* (Figure 14–13). The resistance of a circuit (in ohms) equals the voltage divided by the current (in amperes).

It is very important for technicians to understand Ohm's law. It explains how an increase or decrease in voltage, resistance, or current will affect a circuit.

For example, if the fog light in Figure 14–9 has a 6-ohm resistance, how many amperes does it use to operate? Since cars and light trucks have a 12-volt battery and you know two of the factors in the fog light circuit, it is simple to solve for the third.

$$\text{I (unknown)} = \frac{\text{E (12 volts)}}{\text{R (6 ohms)}}$$

$$\text{I} = \frac{12}{6}$$

$$\text{I} = 2 \text{ amperes}$$

In a clean, well-wired circuit, the fog lights will draw 2 amperes of current. What would happen if resistance in the circuit increases due to corroded or damaged wire or connections? If the corroded connections add 2 ohms of resistance to the fog light circuit, the total resistance is 8 ohms (Figure 14–14). The amount of current flowing through the circuit for the lights decreases.

$$\text{I} = \frac{12}{6+2} = \frac{12}{8}$$

$$\text{I} = 1.5 \text{ amperes}$$

If the lights are designed to operate at 2 amperes, this decrease to 1.5 amperes will cause them to burn dimly. Cleaning the corrosion away or installing new wires and connectors will eliminate the unwanted resistance; the correct amount of current will flow through the circuit, allowing the lamp to burn as brightly as it should.

Power

Electrical power, or the rate of work, is found by multiplying the amount of electrical pressure by the amount of current flow (power = voltage × amperage). Power is measured in watts. Although power

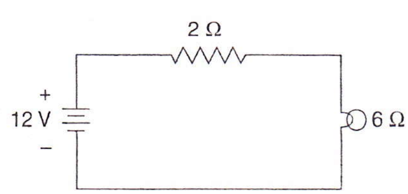


FIGURE 14–14 This is the same circuit as Figure 14–9, but this one has a corroded wire, represented by the additional resistor.

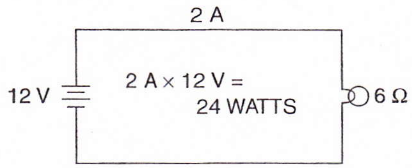


FIGURE 14–15 Electrical power is calculated by multiplying voltage by current.

measurements are rarely, if ever, needed in automotive service, knowing the power requirements of light bulbs, electric motors, and other components is sometimes useful when troubleshooting electrical systems.

Another useful formula is one used to find the power of an electrical circuit expressed in watts.

$$P = E \times I$$

That is, power (P) in watts equals the voltage (E) multiplied by the current (I) in amperes (Figure 14–15). This is known as Watt's law. Looking back at the example of the fog light circuit, we can calculate the amount of power used or heat generated by the fog light.

$$P = 12 \text{ volts} \times 2 \text{ amperes}$$
$$P = 24 \text{ watts}$$

The normal fog light generates 24 watts of power, while the corroded fog light circuit produces the following.

$$P = 12 \text{ volts} \times 1.5 \text{ amperes}$$
$$P = 18 \text{ watts}$$

This reduction in power or heat explains the decrease in bulb brightness.

CONDUCTORS AND INSULATORS

Controlling and routing the flow of electricity requires the use of materials known as conductors and insulators. **Conductors** are materials with a low resistance to the flow of current. If the number of electrons in the outer shell or ring of an atom is less than four, the force holding them in place is weak. The voltage needed to move these electrons and create current flow is relatively small. Most metals, such as copper, silver, and aluminum are excellent conductors.

When the number of electrons in the outer ring are greater than four, the force holding them in orbit is very strong and very high voltages are needed to move them. These materials are known as **insulators**. They resist the flow of current. Thermal plastics are the most common electrical insulators used today. They can resist heat, moisture, and corrosion without breaking down.

CAUTION:

Your body is a good conductor of electricity. Remember this when working on a vehicle's electrical system. Always observe all electrical safety rules. ■

Wire insulation should always be in good condition. Broken, frayed, or damaged insulation that exposes live wires can allow current to flow to unwanted places. These conditions can also create a safety hazard. Replace all wires that have damaged insulation.

Copper wire is by far the most popular conductor used in automotive electrical systems. Wire wound inside electrical units, such as ignition coils and generators, usually has a very thin baked-on insulating coating. External wiring often is covered with a plastic-type insulating material that is highly resistant to environmental factors like heat, vibration, and moisture. Where flexibility is required, the copper wire will be made of a large number of very small strands of wire woven together.

The resistance of a uniform, circular copper wire depends on the length of the wire, the diameter of the wire, and the temperature of the wire. If the length is doubled, the resistance between the wire ends is doubled. The longer the wire, the greater the resistance. If the diameter of a wire is doubled, the resistance for any given length is cut in half. The larger the wire's diameter, the lower the resistance.

In any circuit, the smallest wire that will not cause excessive voltage drop is used to minimize cost.

The other important factor affecting the resistance of a copper wire is temperature. As the temperature increases, the resistance increases. The effects of temperature are very important in the design of electrical equipment. Excessive resistance caused by normal temperature increases can hurt the performance of the equipment.

Heat is developed in any wire carrying current because of the resistance in the wire. If the heat becomes excessive, the insulation will be damaged. Resistance occurs when electrons collide as current flows through the conductor. These collisions cause friction, which in turn generates heat.

Circuits

A complete electrical circuit exists when electrons flow along a path between two points. In a complete circuit, resistance must be low enough to allow the available voltage to push electrons between the two points. Most automotive circuits contain four basic parts.

1. Power sources, such as a battery or alternator that provides the energy needed to cause electron flow.
2. Conductors, such as copper wires that provide a path for current flow.
3. Loads, which are devices that use electricity to perform work, such as light bulbs, electric motors, or resistors.
4. Controllers, such as switches or relays that control or direct the flow of electrons.

There are also three basic types of circuits used in automotive electrical systems. They are series circuits, parallel circuits, and series-parallel circuits. Each circuit type has its own characteristics regarding amperage, voltage, and resistance.

Series Circuits A **series circuit** consists of one or more resistors connected to a voltage source with only one path for electron flow. For example, a simple series circuit consists of a resistor (2 ohms in this example) connected to a 12-volt battery (Figure 14–16A). The current can be determined by applying Ohm's law.

$$I = \frac{E}{R} = \frac{12}{2} = 6 \text{ amperes}$$

Another series circuit may contain a 2-ohm resistor and a 4-ohm resistor connected to a 12-volt battery (Figure 14–16B). The word *series* is given to a circuit in which the same amount of current is present throughout the circuit. The current that flows through one resistor also flows through other resistors in the circuit. As that amount of current leaves the battery, it flows through the conductor to the first resistor. At the resistor, some electrical energy or voltage is consumed as the current flows through it. The decreased amount of voltage is then applied to the next resistor as current flows to it. By the time the current is flowing in the conductor leading back to the battery, all voltage has been consumed. All of the source voltage available to the circuit is dropped by the resistors in the circuit.

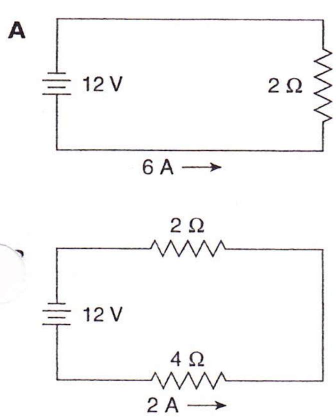


FIGURE 14–16 In a series circuit, the same amount of current flows through the entire circuit.

In a series circuit, the total amount of resistance in the circuit is equal to the sum of all the individual resistors. In the circuit in Figure 14–16B, the total circuit resistance is 4 + 2 = 6 ohms. Based on Ohm's law, current is I = E/R = 12/6 = 2 amperes. In a series circuit, current is constant throughout the circuit. Therefore, 2 amps of current flows through the conductors and both resistors.

Ohm's law can be used to determine the voltage drop across parts of the circuit. For the 2-ohm resistor, E = IR = 2 × 2 = 4 volts. For the 4-ohm resistor, E = 2 x 4 = 8 volts. These values are called **voltage drops**. The sum of all voltage drops in a series circuit must equal the source voltage, or 4 + 8 = 12 volts.

An ammeter connected anywhere in this circuit will read 2 amperes, and a voltmeter connected across each of the resistors will read 4 volts and 8 volts, as shown in Figure 14–17.

All calculations for a series circuit work in the same way no matter how many resistors there are in series. Consider the circuit in Figure 14–18. This circuit has four resistors in series with each other. The total resistance is 12 ohms (5 ohms + 2 ohms + 4 ohms + 1 ohm). Using Ohm's law, we can see that the circuit current is 1 amp (I = E/R = 12/12 = 1 amp). We can also use Ohm's law to determine the voltage drop across each resistor in the circuit. For example, since the circuit current is 1 amp, 4 volts

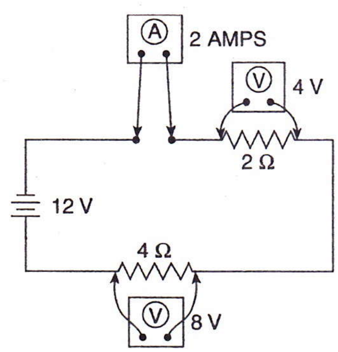


FIGURE 14–17 Measuring the current and voltage drops in the circuit.

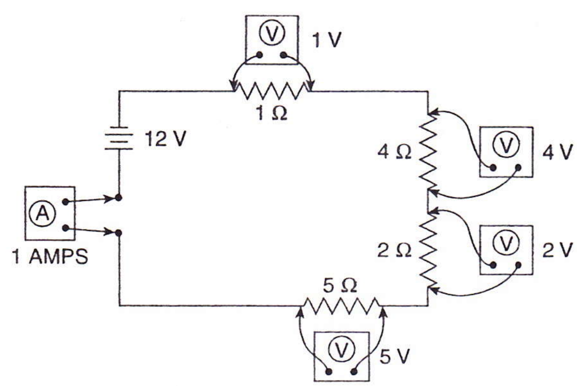


FIGURE 14–18 Values in the series circuit.

are dropped by the 4-ohm resistor (E = I × R = 1 amp × 4 ohms = 4 volts).

A series circuit is characterized by the following three facts.

1. The circuit's current is determined by the total amount of resistance in the circuit; it is constant throughout the circuit.
2. The voltage drops across each resistor are different if the resistance values are different.
3. The sum of the voltage drops equals the source voltage.

Parallel Circuits A **parallel circuit** provides two or more different paths for the current to flow through. Each path has separate resistors (loads) and can operate independently of the other paths. The different paths for current flow are commonly called the legs of a parallel circuit.

A parallel circuit is characterized by the following facts.

1. Total circuit resistance is always lower than the resistance of the leg with the lowest total resistance.
2. The current through each leg will be different if the resistance values are different.
3. The sum of the current on each leg equals the total circuit current.
4. The voltage applied to each leg of the circuit will be dropped across the legs if there are no loads in series with the parallel circuit.

Consider the circuit shown in Figure 14–19. Two 3-ohm resistors are connected to a 12-volt battery. The resistors are in parallel with each other, since the battery voltage (12 volts) is applied to each resistor and they have a common negative lead. The current through each resistor or leg, can be determined by applying Ohm's law. For the 3-ohm resistors, I = E/R = 12/3 = 4 amperes. Therefore, the total circuit current supplied by the battery is 4 + 4 = 8 amperes. Using Ohm's law, we find that 12 volts are dropped by both resistors (Figure 14–20).

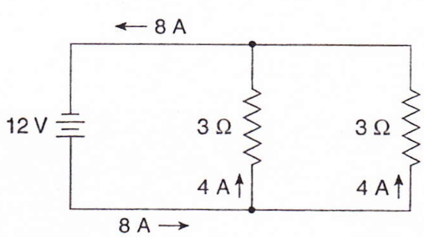


FIGURE 14–19 Simple parallel circuit.

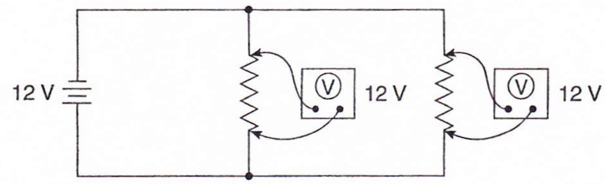


FIGURE 14–20 Parallel circuit with voltage drops shown.

Resistances are not added up to calculate the total resistance in a parallel circuit. Rather, they can be determined by dividing the product of their ohm value by the sum of their ohm values. This formula works when the circuit has two parallel legs.

$$\frac{3 \text{ ohms} \times 3 \text{ ohms}}{3 \text{ ohms} + 3 \text{ ohms}} = \frac{9}{6} = 1.5 \text{ ohms}$$

Total resistance can also be calculated by using Ohm's law if you know the total circuit current and the voltage (R = E/I = 12/8 = 1.5 ohms).

Consider another parallel circuit, Figure 14–21. In this circuit there are two legs and four resistors. Each leg has two resistors in series. One leg has a 4-ohm and a 2-ohm resistor. The total resistance on that leg is 6 ohms. The other leg has a 1-ohm and a 2-ohm resistor. The total resistance of that leg is 3 ohms. Therefore, we have 6 ohms in parallel with 3 ohms.

Current flow through the circuit can be calculated by different methods. Using Ohm's law, we know that I = E/R. If we take the total resistance of each leg and divide it into the voltage, we then know the current through that leg. Since total circuit current is equal to the sum of the current flows through each leg, we simply add the current across each leg together. This will give us total circuit current.

Leg #1: I = E/R = 12/6 = 2 amps
Leg #2: I = E/R = 12/3 = 4 amps
2 amps + 4 amps = 6 amps = total circuit current

Circuit current can also be determined by finding the total resistance of the circuit. To do this, the product-over-sum formula is used. By dividing this total into the voltage, total circuit current is known.

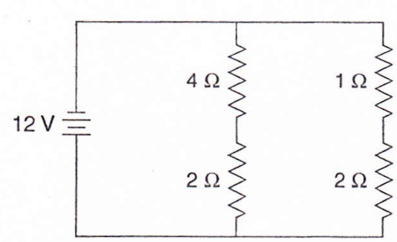


FIGURE 14–21 Series circuits within a parallel circuit.

$$\frac{\text{Leg \#1} \times \text{Leg \#2}}{\text{Leg \#1} + \text{Leg \#2}} = \frac{6 \times 3}{6+3} = \frac{18}{9} = 2 \text{ ohms}$$

since I = E/R, I = 12/2, I = 2 amps (total circuit current)

When a circuit has more than two legs, the reciprocal formula should be used to determine total circuit resistance. The formula follows.

$$\frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots \frac{1}{R_n}}$$

To demonstrate how to use this formula, consider the circuit in Figure 14–22. Here is a parallel circuit with four legs. The resistances across each leg are 4 ohms, 3 ohms, 6 ohms, and 4 ohms. Using the reciprocal formula, we will find that the total resistance of the circuit is 1 ohm. (Note that the total resistance is lower than the leg with the lowest resistance.)

$$\frac{1}{\frac{1}{4} + \frac{1}{3} + \frac{1}{6} + \frac{1}{4}} =$$

$$\frac{1}{\frac{3}{12} + \frac{4}{12} + \frac{2}{12} + \frac{3}{12}} = \frac{1}{\frac{12}{12}} = \frac{1}{1} = 1$$

The total of this circuit could also have been found by calculating the current across each leg then adding them together to get the total circuit current. Using Ohm's law, if you divide the voltage by the total circuit current, you will get total resistance.

Leg #1: I = E/R = 12/4 = 3 amps
Leg #2: I = E/R = 12/3 = 4 amps
Leg #3: I = E/R = 12/6 = 2 amps
Leg #4: I = E/R = 12/4 = 3 amps
Total circuit current = 3 + 4 + 2 + 3 = 12 amps

then,

R = E/I = 12/12 = 1 ohm

Series-Parallel Circuits In a **series-parallel circuit,** both series and parallel combinations exist in the same circuit.

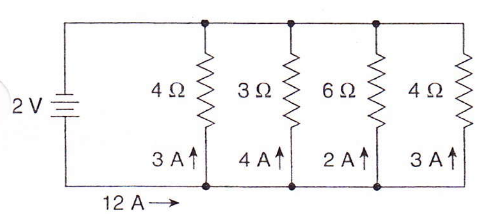


FIGURE 14–22 Parallel circuit with four legs.

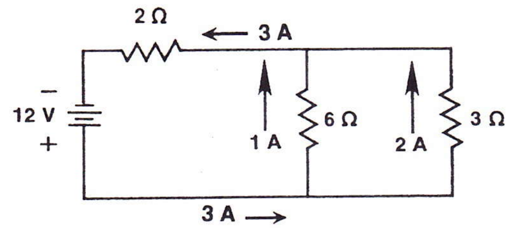


FIGURE 14–23 In a series-parallel circuit, the sum of the currents through the legs must equal the current through the series part of the circuit.

A series-parallel is illustrated in Figure 14–23. The 6- and 3-ohm resistors are in parallel with each other and together are in series with the 2-ohm resistor.

The total current in this circuit is equal to the voltage divided by the total resistance. The total resistance can be determined as follows. The 6- and 3-ohm parallel resistors in Figure 14–23 are equivalent to a 2-ohm resistor, since 6 × 3/6 + 3 = 2. This equivalent 2-ohm resistor is in series with the other 2-ohm resistor. To find the total resistance, add the two resistance values together. This gives a total circuit resistance of 4 ohms (2 + 2 = 4 ohms). The total current, therefore, is I = 12/4 = 3 amperes. This means that 3 amps of current is flowing through the 2-ohm resistor in series and 3 amps are divided between the resistors in parallel. In series-parallel circuits, the sum of the currents, flowing in the parallel legs, must equal that of the series resistors' current.

To find the current through each of the resistors in parallel, find the voltage drop across those resistors first. With 3 amperes flowing through the 2-ohm resistor, the voltage drop across this resistor is E = IR = 3 × 2 = 6 volts, leaving 6 volts across the 6- and 3-ohm resistors. The current through the 6-ohm resistor is I = E/R = 6/6 = 1 ampere, and through the 3-ohm resistor is I = 6/3 = 2 amperes. The sum of these two current values must equal the total circuit current and it does, 1 + 2 = 3 amperes (Figure 14–24). The sum of the voltage drops across the parallel part of the circuit and the series part must also equal source voltage.

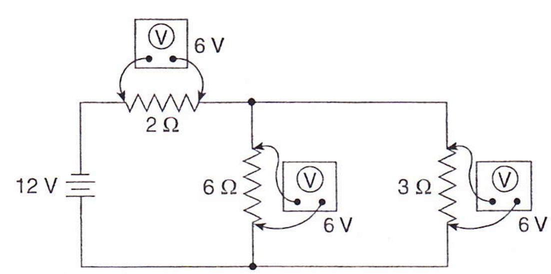


FIGURE 14–24 The circuit in Figure 14–23 with voltage drops shown.

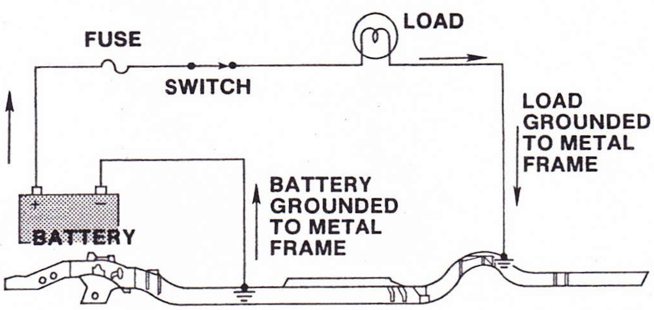


FIGURE 14–25 In most vehicles, the metal frame, engine block, or transmission case is used as a source of ground to complete the circuit back to the battery.

Grounding the Load

In the illustrations used to explain series, parallel, and series-parallel circuits, the return wire from the load or resistor connects directly to the negative terminal of the battery. If this were the case in an actual vehicle, there would be literally hundreds of wires connected to the negative battery terminal.

To avoid this, auto manufacturers use a wiring style that involves using the vehicle's metal frame components as part of the return circuit. Using the chassis as the negative wire is often referred to as **grounding**. The wire or metal mounting that serves as the contact to the chassis is commonly called the **ground wire** or lead. As shown in Figure 14–25, the load is grounded directly to the metal frame. The metal frame then acts as the return wire in the circuit. Current passes from the battery, through the load, and into the frame. The frame is connected to the negative terminal of the battery through the battery's ground wire.

An electrical component, such as an alternator, may be mounted directly to the engine block, transmission case, or frame. This direct mounting effectively grounds the component without the use of a separate ground wire. In other cases, however, a separate ground wire must be run from the component to the frame or another metal part to ensure a good connection for the return path. The increased use of plastics and other nonmetallic materials in body panels and engine parts has made electrical grounding more difficult. To ensure good grounding back to the battery, some manufacturers now use a network of common grounding terminals and wires (Figure 14–26).

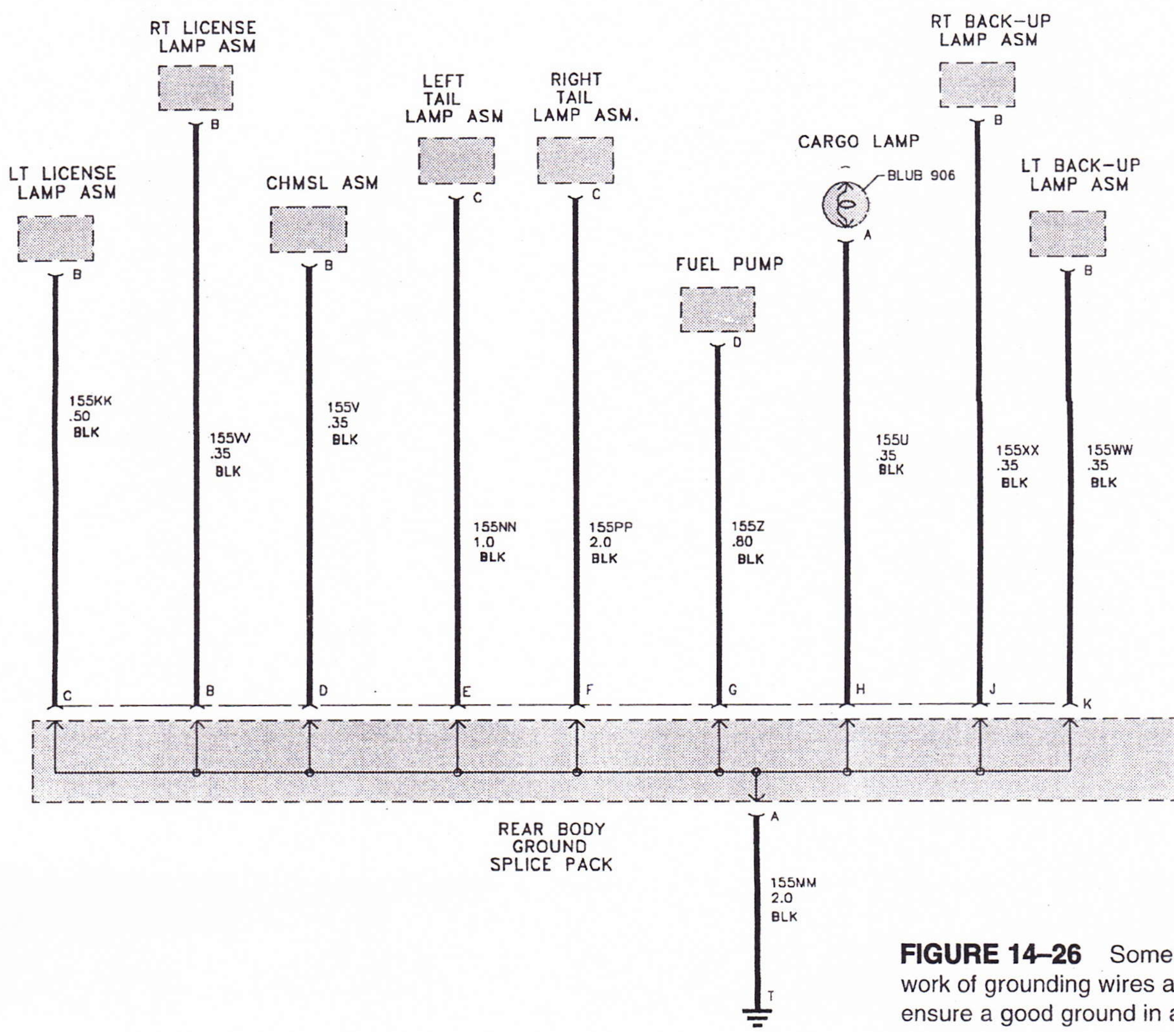


FIGURE 14–26 Some vehicles use a network of grounding wires and terminals to ensure a good ground in all electrical circuits.

Circuit Components

Automotive electrical circuits contain a number of different types of electrical devices. The more common components are outlined in the following sections.

Resistors As shown in the explanation of simple circuit design, resistors are used to limit current flow (and thereby voltage) in circuits where full current flow and voltage are not needed or desired. Resistors are devices specially constructed to put a specific amount of resistance into a circuit. In addition, some other components use resistance to produce heat and even light. An electric window defroster is a specialized type of resistor that produces heat. Electric lights are resistors that get so hot they produce light.

Automotive circuits typically contain these types of resistors: fixed value, stepped or tapped, and variable.

Fixed value resistors are designed to have only one rating, which should not change. These resistors are used to decrease the amount of voltage applied to a component, such as an ignition coil. Often manufacturers use a special wire, called **resistor wire**, to limit current flow and voltage in a circuit. This wire looks much like normal wire but is not a good conductor and is marked as a resistor.

Tapped or **stepped resistors** are designed to have two or more fixed values, available by connecting wires to the several taps of the resistor. Heater motor resistor packs, which provide for different fan speeds, are an example of this type of resistor (Figure 14–27).

Variable resistors are designed to have a range of resistances available through two or more taps and a control. Two examples of this type of resistor are **rheostats** and **potentiometers**. Rheostats (Figure 14–28) have two connections, one to the fixed end of a resistor and one to a sliding contact with the resistor. Moving the control moves the sliding contact away from or toward the fixed end tap, increasing or decreasing the resistance. Potentiometers (Figure 14–29) have three connections, one at each end of the resistance and one connected to a sliding contact with the resistor. Moving the control moves the sliding contact away from one end of the resistance but toward the other end. These are called potentiometers because different amounts of potential or voltage can be sent to another circuit. As the sliding contact moves, it picks up a voltage equal to the source voltage minus the amount dropped by the resistor, so far (Figure 14–30).

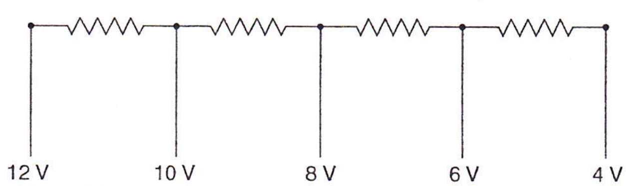


FIGURE 14–27 Stepped resistor.

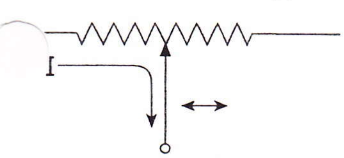


FIGURE 14–28 Rheostat.

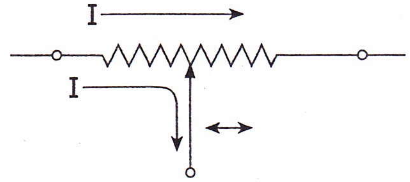


FIGURE 14–29 Potentiometer.

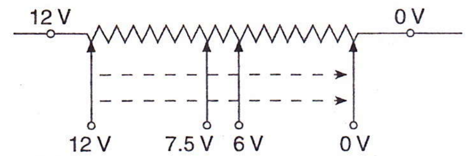


FIGURE 14–30 Voltage across a potentiometer.

Another type of variable resistor is the **thermistor**. This type of resistor is designed to change its resistance value as its temperature changes. Although most resistors are carefully constructed to maintain their rating within a few ohms through a range of temperatures, the thermistor is designed to change its rating. Thermistors are used to provide compensating voltage in components or to determine temperature. As a temperature sensor, the thermistor is connected to a voltmeter calibrated in degrees. As the temperature rises or falls, the resistance also changes, and so does the voltage in the circuit. These changes are read on the temperature gauge. Thermistors are also commonly used to sense temperature and send a signal back to a control unit. The control unit interprets the signal as a temperature value (Figure 14–31).

Circuit Protective Devices When overloads or shorts in a circuit cause too much current to flow, the wiring in the circuit heats up, the insulation melts, and a fire can result, unless the circuit has some kind of protective device. Fuses, fuse links, maxi-fuses, and circuit breakers are designed to provide protection from high current. They may be used singularly or in combination. Typical symbols for protection devices are shown in Figure 14–32.

WARNING!

Fuses and other protection devices normally do not wear out. They go bad because something went wrong. Never replace a fuse or fusible link, or reset a circuit breaker, without finding out why it went bad. ■

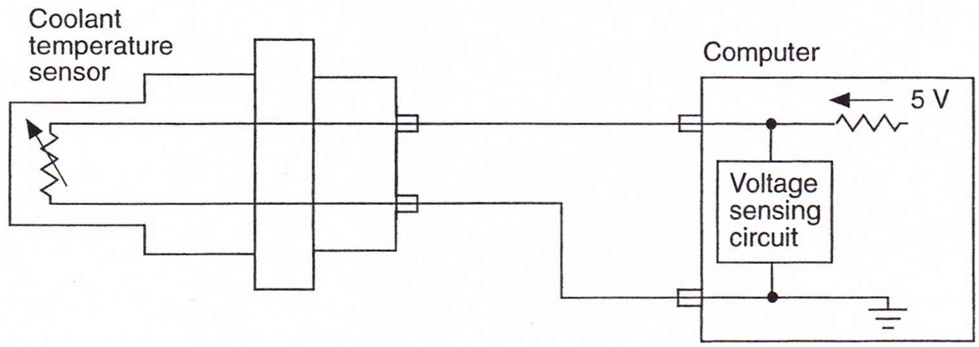


FIGURE 14–31 A thermistor is used to measure temperature. The sensing unit measures the change in resistance and translates this into a temperature value.

FUSES There are three basic types of fuses in automotive use: cartridge, blade, and ceramic (Figure 14–33). The **cartridge fuse** is found on most older domestic cars and a few imports. It is composed of a strip of low melting metal enclosed in a transparent glass or plastic tube. To check this type of fuse, look for a break in the internal metal strip. Discoloration of the glass cover or glue bubbling around the metal end caps is an indication of overheating. Late-model domestic vehicles and many imports use **blade** or **spade fuses**. To check the fuse, pull it from the fuse panel and look at the fuse element through the transparent plastic housing. Look for internal breaks and discoloration. The **ceramic fuse** is used on many European imports. The core is a ceramic insulator with a conductive metal strip along one side. To check this type of fuse, look for a break in the contact strip on the outside of the fuse. All types of fuses can be checked with an ohmmeter or testlight. If the fuse is good, there will be continuity through it.

Fuses are rated by the current at which they are designed to blow. A three-letter code is used to indicate the type and size of fuses. Blade fuses have codes ATC or ATO. All glass SFE fuses have the same diameter, but the length varies with the current rating. Ceramic fuses are available in two sizes, code GBF (small) and the more common code GBC (large). The amperage rating is also embossed on the insulator. Codes, such as AGA, AGW, and AGC, indicate the length and diameter of the fuse. Fuse lengths in each of these series is the same, but the current rating can vary. The code and the current rating is usually stamped on the end cap.

The current rating for blade fuses is indicated by the color of the plastic case (Table 14–1). In addition, it is usually marked on the top. The insulator on ceramic fuses is color coded to indicate different current ratings.

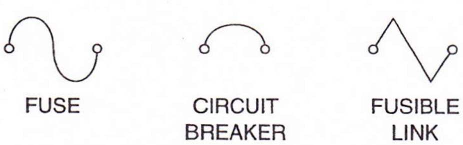


FIGURE 14–32 Electrical symbols for common circuit protection devices.

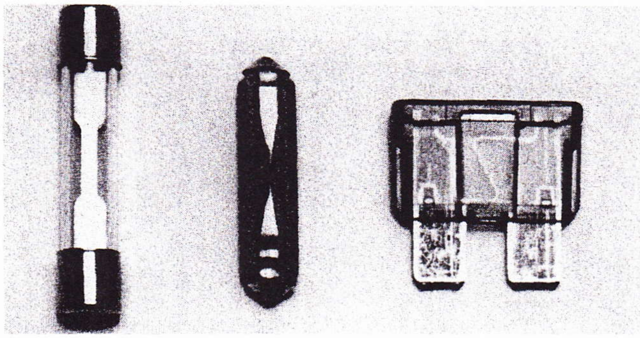


FIGURE 14–33 (A) Cartridge fuse, (B) ceramic fuse, and (C) blade fuse.

CUSTOMER CARE

Advise your customers to carry an assortment of spare fuses in the car's glove compartment. It is difficult to know when one will blow. Also, show the customer how to borrow a fuse from a less critical circuit. For example, it is possible to do without power for the radio or air conditioner, if a fuse is needed for the headlights or brake lights. Make certain, however, that the fuse borrowed and later replaced has the same current rating. Remember that a blown fuse was caused by something going wrong. Inform the customer that replacing the fuse may or may not give a temporary solution to the problem. ■

Fuses are located in a box or panel (Figure 14–34), usually under the dashboard, behind a panel in the foot well, or in the engine compartment. Fuses are generally numbered, and the main components abbreviated. On late-model cars, there may be icons or symbols indicating which circuits they serve. This identification system is covered in more detail in the owner's and service manuals.

TABLE 14–1 TYPICAL COLOR CODING OF PROTECTIVE DEVICES

Blade Fuse Color Coding	
Ampere Rating	**Housing Color**
4	pink
5	tan
10	red
15	light blue
20	yellow
25	natural
30	light green
Fuse Link Color Coding	
Wire Link Size	**Insulation Color**
20 GA	blue
18 GA	brown or red
16 GA	black or orange
14 GA	green
12 GA	gray
Maxi-Fuse Color Coding	
Ampere Rating	**Housing Color**
20	yellow
30	light green
40	amber
50	red
60	blue

Sometimes it is necessary to protect a device in a portion of a circuit even though the entire circuit is protected by a fuse in the fuse panel. This is done by installing an **in-line fuse** in the wire that carries current to the device. In-line fuses are primarily used on accessories that are very sensitive to power surges, such as radios and compact disc players. They are also used with added-on units like driving lights and power antennas. Normally, these fuses are close to the units they protect.

There are several types of in-line fuse carriers. One of the most popular and easiest to install is shown in Figure 14–35.

SHOP TALK

To calculate the correct fuse rating, use Watt's law: watts ÷ volts = amperes. For example, if you are installing a 55-watt pair of fog lights, divide 55 by the battery voltage (12 volts) to find out how much current the circuit has to carry. Since 55 ÷ 12 = 4.58, the current is approximately 5 amperes. To allow for current surges, the correct in-line fuse should be rated slightly higher than the normal current flow. In this case, an 8- or 10-ampere fuse would do the job. ■

FUSE LINKS Fuse or **fusible links** are used in circuits when limiting the maximum current is not extremely critical. They are often installed in the positive battery lead to the ignition switch and other circuits that have power with the key off. Fusible links

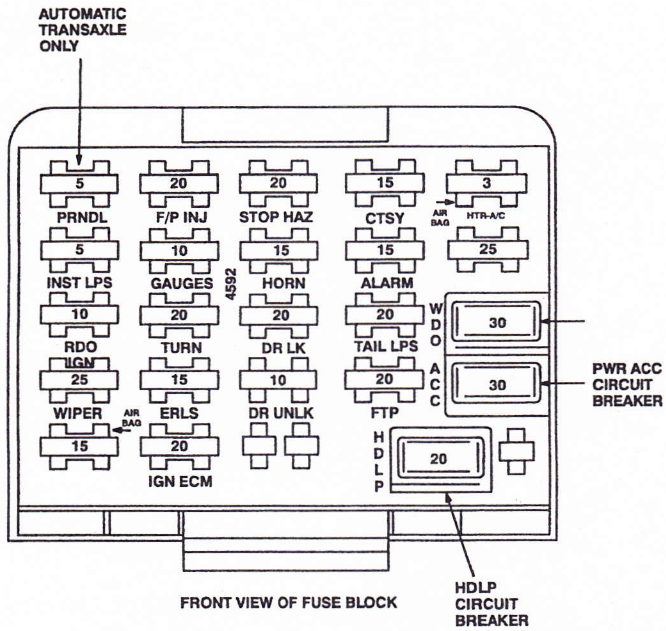


FIGURE 14–34 Typical fuse box or panel.

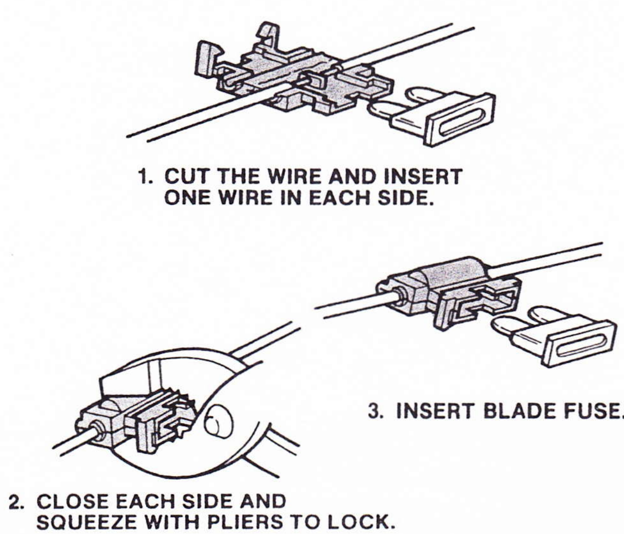


FIGURE 14–35 In-line blade fuse carrier.

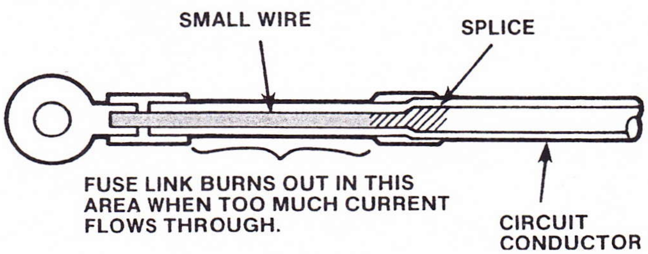


FIGURE 14–36 Typical fuse link.

are normally found in the engine compartment near the battery. Fusible links are also used when it would be awkward to run wiring from the battery to the fuse panel and back to the load.

A fuse link (Figure 14–36) is a short length of small gauge wire installed in a conductor. Because the fuse link is a lighter gauge of wire than the main conductor, it melts and opens the circuit before damage can occur in the rest of the circuit. Fuse link wire is covered with a special insulation that bubbles when it overheats, indicating that the link has melted. If the insulation appears good, pull lightly on the wire. If the link stretches, the wire has melted. Of course, when it is hard to determine if the fuse link is burned out, check for continuity through the link with a testlight or ohmmeter.

WARNING!

Do not mistake a resistor wire for a fuse link. A resistor wire is generally longer and is clearly marked "Resistor—do not cut or splice." ■

To replace a fuse link, cut the protected wire where it is connected to the fuse link. Then, tightly crimp or solder a new fusible link of the same rating as the original link (Figure 14–37). Since the insulation on the manufacturer's fuse link is flameproof, never fabricate a fuse link from ordinary wire because the insulation may not be flameproof.

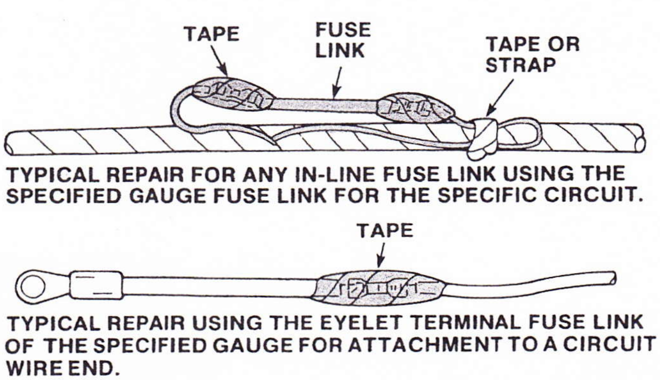


FIGURE 14–37 Typical fuse link repair.

CAUTION:

Always disconnect the battery ground cable prior to servicing any fuse link. ■

MAXI-FUSES Many late-model vehicles use **maxi-fuses** instead of fusible links. Maxi-fuses look and operate like two-prong, blade, or spade fuses, except they are much larger and can handle more current. (Typically, a maxi-fuse is four to five times larger.) Maxi-fuses are located in their own underhood fuse block.

Maxi-fuses are easier to inspect and replace than are fuse links. To check a maxi-fuse, look at the fuse element through the transparent plastic housing. If there is a break in the element, the maxi-fuse has blown. To replace it, pull it from its fuse box or panel. Always replace a blown maxi-fuse with a new one having the same ampere rating.

Maxi-fuses allow the vehicle's electrical system to be broken down into smaller circuits that are easy to diagnose and repair. For example, in some vehicles a single fusible link controls one-half or more of all circuitry. If it burns out, many electrical systems are lost. By replacing this single fusible link with several maxi-fuses, the number of systems lost due to a problem in one circuit is drastically reduced. This makes it easy to pinpoint the source of trouble.

CIRCUIT BREAKERS Some circuits are protected by **circuit breakers** (abbreviated c.b. in the fuse chart of a service manual). They can be fuse panel mounted or in-line. Like fuses, they are rated in amperes.

Each circuit breaker conducts current through an arm made of two types of metal bonded together (bimetal arm). If the arm starts to carry too much current, it heats up. As one metal expands faster than the other, the arm bends, opening the contacts. Current flow is broken. A circuit breaker can be cycling (Figure 14–38) or must be manually reset.

In the cycling type, the bimetal arm will begin to cool once the current to it is stopped. Once it returns to its original shape, the contacts are closed and

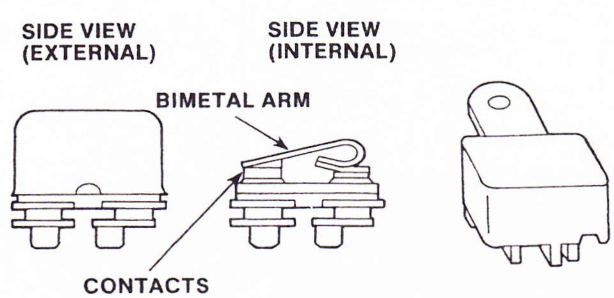


FIGURE 14–38 Cycling circuit breaker.

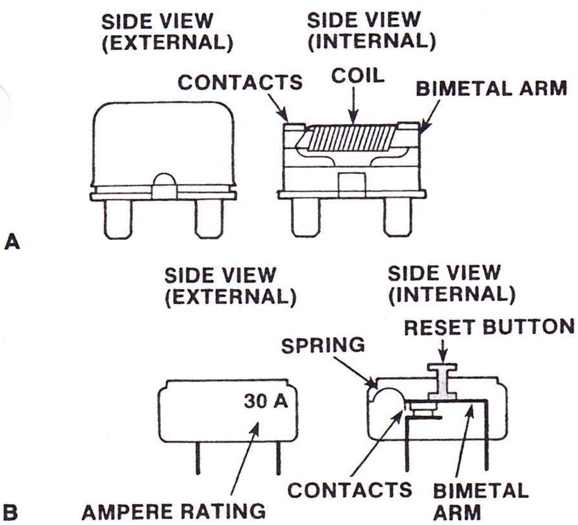


FIGURE 14–39 Resetting noncycling circuit breakers by (A) removing power from the circuit and (B) depressing a reset button.

power is restored. If the current is still too high, the cycle of breaking the circuit will be repeated.

Two types of noncycling or resettable circuit breakers are used. One is reset by removing the power from the circuit. There is a coil wrapped around a bimetal arm (Figure 14–39A). When there is excessive current and the contacts open, a small current passes through the coil. This current through the coil is not enough to operate a load, but it does heat up both the coil and the bimetal arm. This keeps the arm in the open position until power is removed. The other type is reset by depressing a reset button. A spring pushes the bimetal arm down and holds the contacts together (Figure 14–39B). When an overcurrent condition exists and the bimetal arm heats up, the bimetal arm bends enough to overcome the spring and the contacts snap open. The contacts stay open until the reset button is pushed, which snaps the contacts together again.

Voltage Limiter Some instrument panel gauges are protected against voltage fluctuations that could damage the gauges or give erroneous readings. A **voltage limiter** restricts voltage to the gauges to a particular amount. The limiter contains a heating coil, a bimetal arm, and a set of contacts. When the ignition is in the on or accessory position, the heating coil heats the bimetal arm, causing it to bend and open the contacts. This action results in voltage from both the heating coil and the circuit. When the arm cools down to the point that the contacts close, the cycle is repeated. The rapid opening and closing of the contacts produces a pulsating voltage at the output terminal averaging about 5 volts.

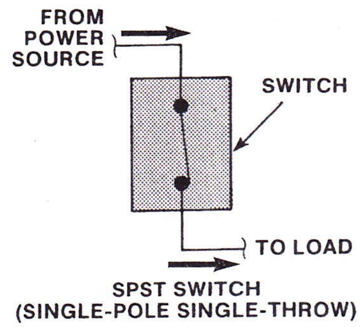


FIGURE 14–40 SPST hinged-pawl switch diagram.

Switches Electrical circuits are usually controlled by some type of switch. Switches do two things. They turn the circuit on or off, or they direct the flow of current in a circuit. Switches can be under the control of the driver or can be self-operating through a condition of the circuit, the vehicle, or the environment.

Contacts in a switch can be of several types, each named for the job they do or the sequence in which they work. A hinged-pawl switch (Figure 14–40) is the simplest type of switch. It either makes (allows for) or breaks (opens) current flow in a single conductor or circuit. This type of switch is a single-pole, single-throw (**SPST**) switch. The **throw** refers to the number of output circuits, and the **pole** refers to the number of input circuits made by the switch.

Another type of SPST switch is a momentary contact switch (Figure 14–41). The spring-loaded contact on this switch keeps it from closing the circuit except when pressure is applied to the button. A horn switch is this type of switch. Because the spring holds the contacts open, the switch has a further designation: **normally open**. In the case where the contacts are held closed except when the button is pressed, the switch is designated **normally closed**. A normally closed momentary contact switch is the type of switch used to turn on the courtesy lights when one of the vehicle's doors is opened.

Single-pole, double-throw (**SPDT**) switches have one wire in and two wires out. Figure 14–42 shows an SPDT hinged-pawl switch that feeds either the high-beam or low-beam headlight circuit. The dotted

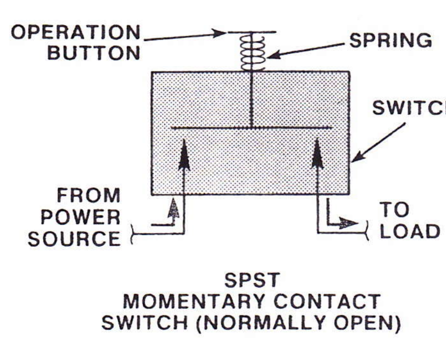


FIGURE 14–41 SPST momentary contact switch diagram.

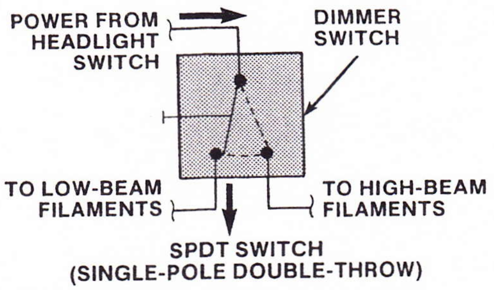


FIGURE 14–42 SPDT headlight dimmer switch.

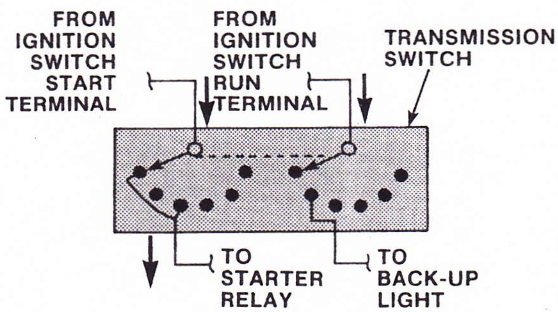


FIGURE 14–43 MPMT neutral start safety switch.

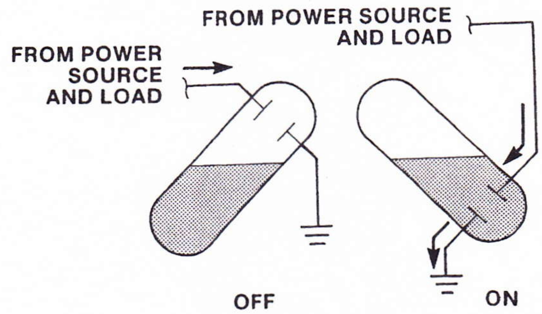


FIGURE 14–44 Typical mercury switch.

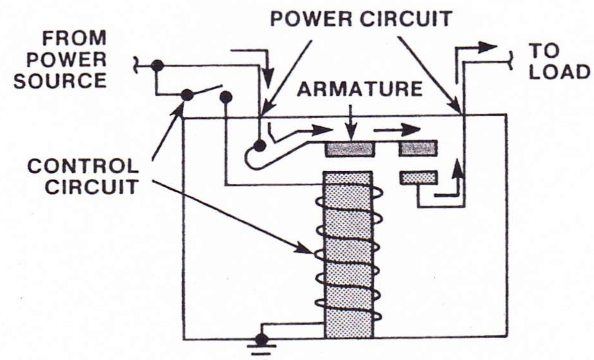


FIGURE 14–45 Typical electrical relay design.

lines in the symbol show movement of the switch pawl from one contact to the other.

Switches can be designed with a great number of poles and throws. The transmission neutral start switch shown in Figure 14–43, for instance, has two poles and six throws and is referred to as a multiple-pole, multiple-throw (**MPMT**) switch. It contains two movable wipers that move in unison across two sets of terminals. The dotted line shows that the wipers are mechanically linked, or **ganged**. The switch closes a circuit to the starter in either P (park) or N (neutral) and to the back-up lights in R (reverse).

Most switches are combinations of hinged-pawl and push-pull switches, with different numbers of poles and throws. Some special switches are required, however, to satisfy the circuits of modern automobiles. A mercury switch is sometimes used to detect motion in a component, such as the one used in the engine compartment to turn on the compartment light.

Mercury is a very good conductor of electricity. In the mercury switch, a capsule is partially filled with mercury (Figure 14–44). In one end of the capsule are two electrical contacts. The switch is attached to the hood or luggage compartment lid. Normally, the mercury is in the end opposite to the contacts. When the lid is opened, the mercury flows to the contact end and provides a circuit between the electrical contacts.

A temperature-sensitive switch usually contains a bimetallic element heated either electrically or by some component where the switch is used as a **sensor**. When engine coolant is below or at normal operating temperature, the engine coolant temperature sensor is in its normally open condition. If the coolant exceeds the temperature limit, the bimetallic element bends the two contacts together and the switch is closed to the indicator or the instrument panel. Other applications for heat-sensitive switches are time-delay switches and flashers.

Relays A **relay** is an electric switch that allows a small amount of current to control a high current circuit (Figure 14–45). When the control circuit switch is open, no current flows to the coil of the relay, so the windings are de-energized. When the switch is closed, the coil is energized, turning the soft iron core into an electromagnet and drawing the armature down. This closes the power circuit contacts, connecting power to the load circuit. When the control switch is opened, current stops flowing in the coil and the electromagnet disappears. This releases the armature, which breaks the power circuit contacts.

Solenoids **Solenoids** are also electromagnets with movable cores used to change electrical current flow into mechanical movement. They can also close contacts, acting as a relay at the same time.

Capacitors (Condensers) **Capacitors** are constructed from two or more sheets of electrically conducting material with a nonconducting or **dielectric** (anti-electric) material placed between them. Conductors

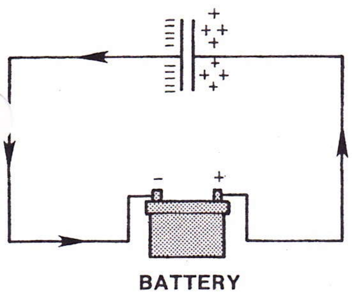


FIGURE 14–46
Charging a capacitor.

are connected to the two sheets. Capacitors are devices that oppose a change of voltage.

If a battery is connected to a capacitor as shown in Figure 14–46, the capacitor will be charged when current flows from the battery to the plates. This current flow will continue until the plates have the same voltage as the battery. At this time, the capacitor is charged.

The capacitor remains charged until a circuit is completed between the two plates. If the charge is routed through a voltmeter, the capacitor will discharge with the same voltage as the battery that charged it. This statement explains why capacitors are commonly used to filter or clean up voltage signals, such as sound from a stereo. Current can only flow during the period of time that a capacitor is either charging or discharging.

Automotive capacitors are normally encased in metal. The grounded case provides a connection to one set of conductor plates and an insulated lead connects to the other set.

Variable capacitors are called **trimmers** or tuners and are rated very low in capacity because of the reduced size of their conducting plates. For this reason, they are only used in very sensitive circuits, such as radios and other electronic applications.

Wiring Electrical wires are used to conduct electricity to operate the electrical and electronic devices in a vehicle. There are two basic types of wires used: solid and stranded. **Solid wires** are single-strand conductors. **Stranded wires** are made up of a number of small solid wires twisted together to form a single conductor. Stranded wires are the most commonly used type of wire in an automobile. Electronic units, such as computers, use specially shielded, twisted cable for protection from unwanted induced voltages that can interfere with computer functions. In addition, some solid state components use printed circuits.

The current-carrying capacity and the amount of voltage drop in an electrical wire are determined by its length and gauge (size). The wire sizes are established by the Society of Automotive Engineers (SAE), which is the American wire gauge (**AWG**) system. Sizes are identified by a numbering system ranging from number 0 to 20, with number 0 being the largest and number 20 the smallest in a cross-sectional area (Table 14–2). Most automotive wiring ranges from number 10 to 18 and the battery cables are normally at least number 4 gauge. Battery cables are large gauge wires capable of carrying the high currents for the starter motor.

TABLE 14–2 WIRE GAUGE SIZES

Metric Size (mm^2)	Wire Size	Ampere Capacity
0.5	20	4
0.8	18	6
1.0	16	8
2.0	14	15
3.0	12	20
5.0	10	30
8.0	8	40
13.0	6	50
19.0	4	60

Automotive wiring can also be classified as primary or secondary. Primary wiring carries low voltage to all the electrical systems of the vehicle except to secondary circuits of the ignition system. Secondary wire, also called **high-tension cable**, has extra thick insulation to carry high voltage from the ignition coil to the spark plugs. The conductor itself is designed for low currents.

The proper selection of the correct gauge wire is very important. The wire should be large enough to assure safe and reliable performance. However, overly large wires add weight and expense to the vehicle. If too small a wire is used, a voltage drop can occur due to electrical resistance. The two factors that should always be considered when the size of a wire is determined are the total amperage the circuit carries and the total length of wire used in each circuit, including the return. Allowance for the return circuits, including grounded returns, has been computed in Table 14–3. The length of cable should be determined by totaling both wires on a two-wire circuit.

Wires are commonly grouped together in harnesses. A single-plug harness connector may form the connections for four, six, or more circuits. Harnesses and harness connectors help organize the vehicle's electrical system and provide a convenient starting point for tracking and testing many circuits. Most major wiring harness connectors are located in a vehicle's dash or fire wall area (Figure 14–47).

Printed Circuits Many late-model vehicles use flexible printed circuits (Figure 14–48) and printed circuit boards. Both types of printed circuits allow for

TABLE 14–3 WIRE SIZE AND LENGTH

Total Approximate Circuit Amperes	Wire Gauge (for Length in Feet)								
12V	3	5	7	10	15	20	25	30	40
1.0	18	18	18	18	18	18	18	18	18
1.5	18	18	18	18	18	18	18	18	18
2	18	18	18	18	18	18	18	18	18
3	18	18	18	18	18	18	18	18	18
4	18	18	18	18	18	18	18	16	16
5	18	18	18	18	18	18	18	16	16
6	18	18	18	18	18	18	16	16	16
7	18	18	18	18	18	18	16	16	14
8	18	18	18	18	18	16	16	16	14
10	18	18	18	18	16	16	16	14	12
11	18	18	18	18	16	16	14	14	12
12	18	18	18	18	16	16	14	14	12
15	18	18	18	18	14	14	12	12	12
18	18	18	16	16	14	14	12	12	10
20	18	18	16	16	14	12	10	10	10
22	18	18	16	16	12	12	10	10	10
24	18	18	16	16	12	12	10	10	10
30	18	16	16	14	10	10	10	10	10
40	18	16	14	12	10	10	8	8	6
50	16	14	12	12	10	10	8	8	6
100	12	12	10	10	6	6	4	4	4
150	10	10	8	8	4	4	2	2	2
200	10	8	8	6	4	4	2	2	1

Note: 18 AWG as indicated above this line could be 20 AWG electrically. 18 AWG is recommended for mechanical strength.

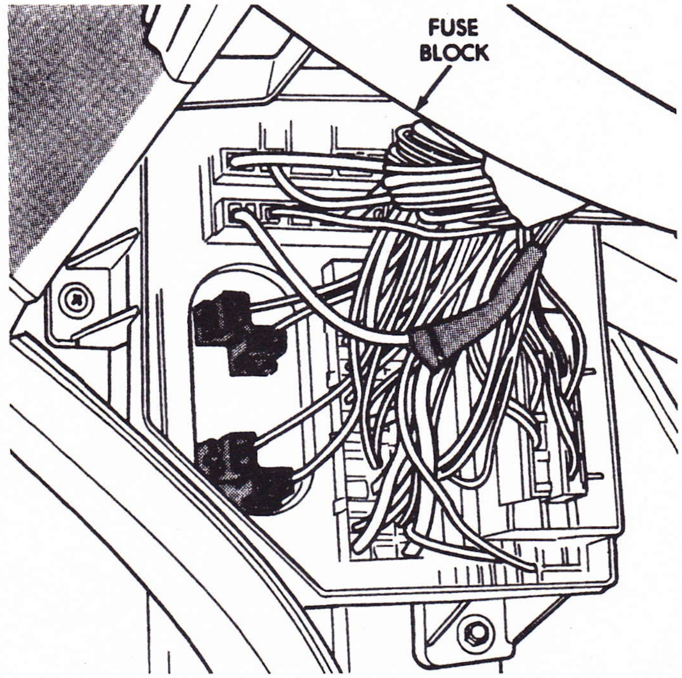


FIGURE 14–47 Typical front wiring harness.

complete circuits to many components without having to run dozens of wires. Printed circuit boards are typically contained in a housing, such as the engine control module. These boards are not serviceable and in some cases not visible. When these boards fail, the entire unit is replaced.

A flexible printed circuit saves weight and space. It is made of thin sheets of nonconductive plastic onto which conductive metal, such as copper, has been deposited. Parts of the metal are then etched or eaten away by acid. The remaining metal lines form the conductors for the various circuits on the board. The printed circuit is normally connected to the power supply or ground wiring through the use of plug-in connectors mounted on the circuit sheet.

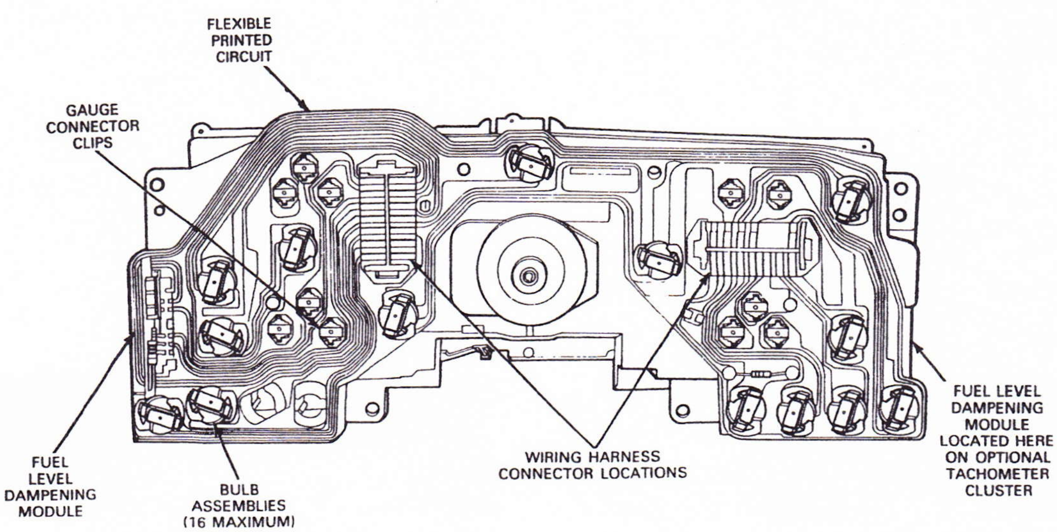


FIGURE 14–48 Typical printed circuit board.

There are several precautions that should be observed when working on a printed circuit.

1. Never touch the surface of the board. Dirt, salts, and acids on your fingers can etch the surface and set up a resistive condition. It is possible to knock out an entire section of the dash with a fingerprint.
2. The copper conductors can be cleaned with a commercial cleaner or by lightly rubbing a pencil eraser across the surface.
3. A printed circuit board is easily damaged because it is very thin. Be careful not to tear the surface especially when plugging in connectors or bulbs.

Electrical Wiring Diagrams Wiring diagrams, sometimes called **schematics**, are used to show how circuits are constructed. A typical service manual contains dozens of wiring diagrams vital to the diagnosis and repair of the vehicle.

A wiring diagram does not show the actual position of the parts on the vehicle or their appearance, nor does it indicate the length of the wire that runs between components. It usually indicates the color of the wire's insulation and sometimes the wire gauge size. Typically, the primary wire insulation is color coded as shown in Table 14–4. The first letter in a combination of letters usually indicates the base color. The second letter usually refers to the strip color (if any). Tracing a circuit through a vehicle is basically a matter of following the colored wires.

TABLE 14–4 COMMON WIRE COLOR CODES

Color	Abbreviations		
Aluminum	AL		
Black	BLK	BK	B
Blue (Dark)	BLU DK	DB	DK BLU
Blue (Light)	BLU LT	LB	LT BLU
Brown	BRN	BR	BN
Glazed	GLZ	GL	
Gray	GRA	GR	G
Green (Dark)	GRN DK	DG	DK GRN
Green (Light)	GRN LT	LG	LT GRN
Maroon	MAR	M	
Natural	NAT	N	
Orange	ORN	O	ORG
Pink	PNK	PK	P
Purple	PPL	PR	
Red	RED	R	RD
Tan	TAN	T	TN
Violet	VLT	V	
White	WHT	W	WH
Yellow	YEL	Y	YL

Many different symbols are also used to represent components such as resistors, batteries, switches, transistors, and many other items. Some of these symbols have already been shown earlier in the chapter. Other common symbols are shown in Figure 14–49. Part of a typical wiring diagram is shown in Figure 14–50, notice that the components are also labeled.

Wiring diagrams can become quite complex. To avoid this, most diagrams usually illustrate only one distinct system, such as the backup light circuit, oil pressure indicator light circuit, or wiper motor circuit. In more complex ignition, electronic fuel injection, and computer control systems, a diagram may be used to illustrate only part of the entire circuit.

USING SERVICE MANUALS

Keep in mind that electrical symbols are not standardized throughout the automotive industry. Different manufacturers may have different methods of representing certain components, particularly the less common ones. Always refer to the symbol reference charts, wire color code charts, and abbreviation tables listed in the vehicle's service manual to avoid confusion when reading wiring diagrams. Also, most diagrams are designed to be read from left to right, top to bottom, just as you would a book. ■

Electrical Problems All electrical problems can be classified into one of three categories: opens, shorts, or high-resistance problems. Identifying the type of problem allows you to identify the correct tests to perform when diagnosing an electrical problem. The different classifications of electrical problems follow.

An open occurs when a circuit has a break in the wire. Without a completed path, current cannot flow and the load or component cannot work. An open circuit can be caused by a disconnected wire, a broken wire, or a switch in the OFF position. Although voltage will be present up to the open point there is no current flow. Without current flow, there are no voltage drops across the various loads.

A short results from an unwanted path for current. Shorts cause an increase in current flow. This increased current flow can burn wires or components. Sometimes two circuits become shorted together. When this happens, one circuit powers another. This may result in strange happenings, such as the horn sounding every time the brake pedal is depressed. In

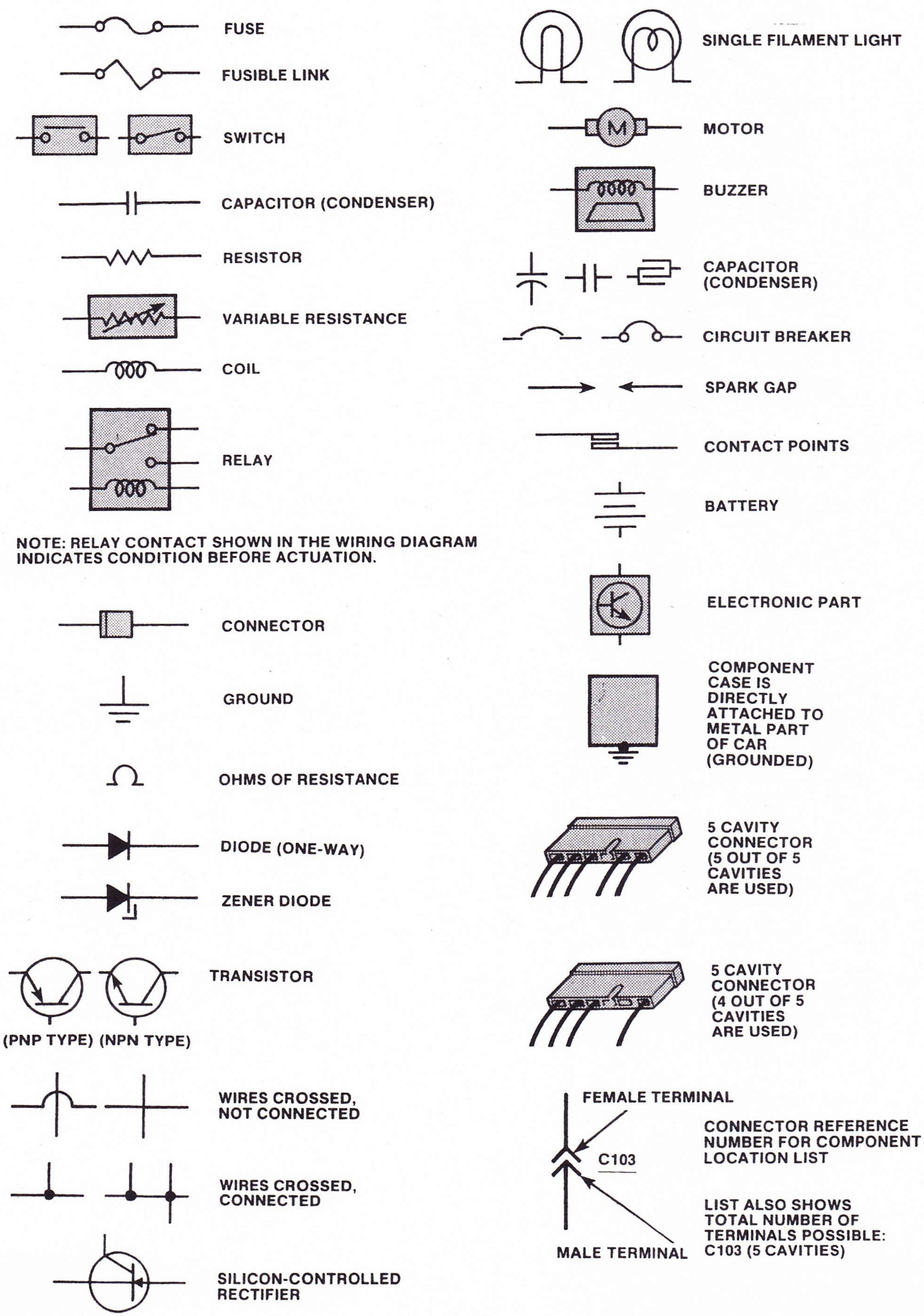


FIGURE 14–49 Common electrical symbols used on wiring diagrams.

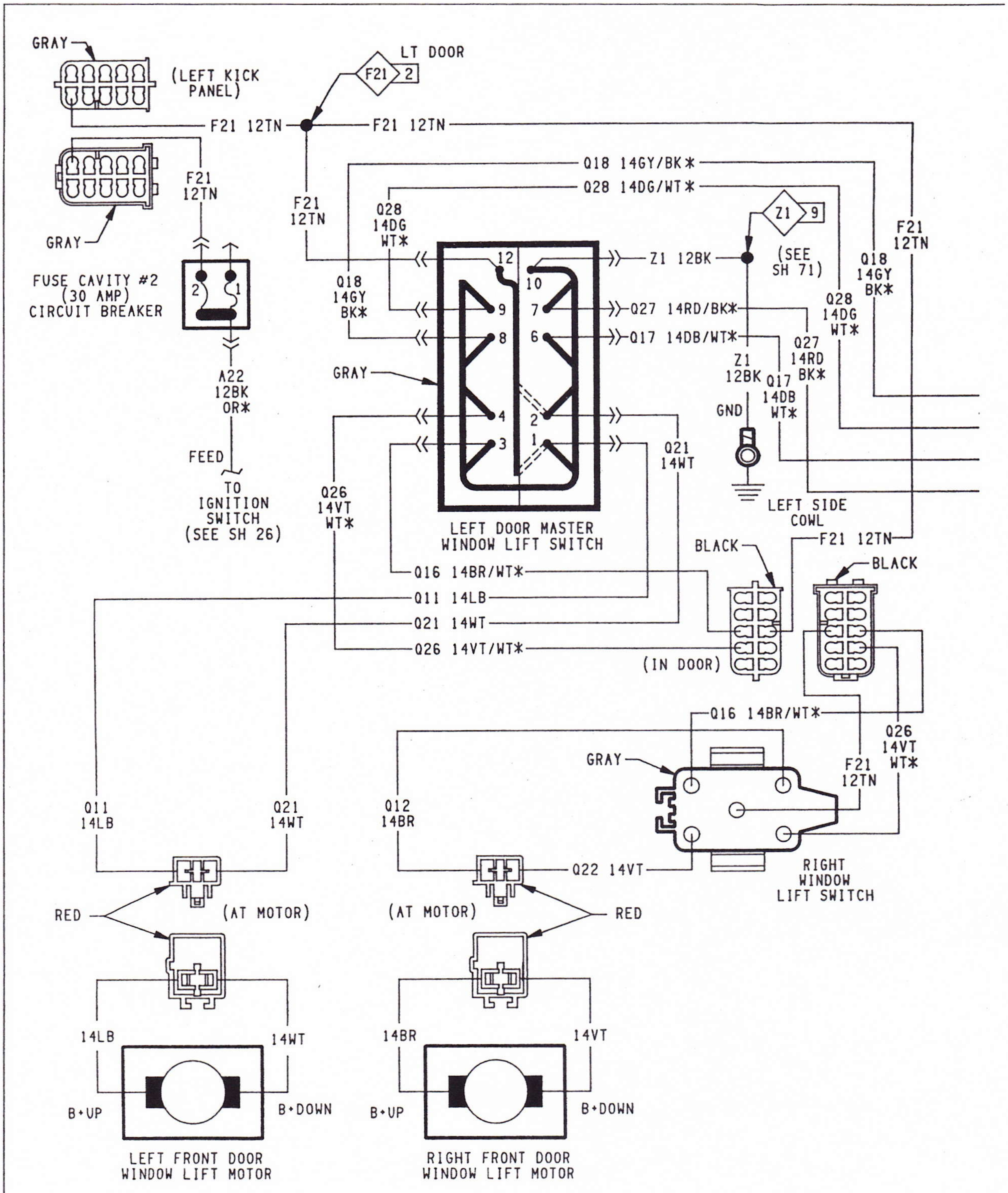


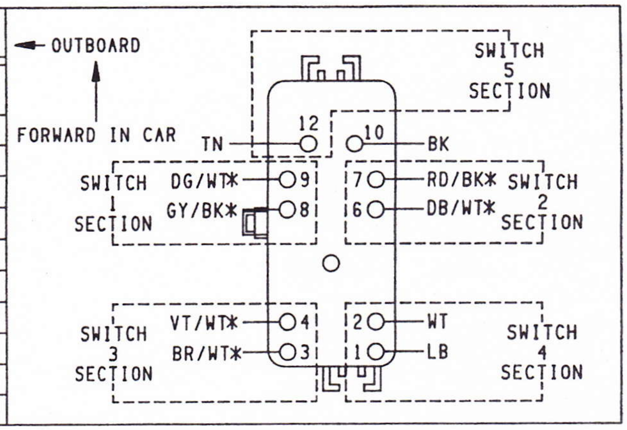
FIGURE 14–50 One part of a large wiring diagram.

this case, the brake light circuit is shorted to the horn circuit. Improper wiring or damaged insulation are the two major causes of short circuits.

A short can also be an unwanted short to ground. This problem provides a low resistance path to ground. This problem causes extremely high current flow, which will damage wires and electrical components. Some call this problem a grounded circuit.

High-resistance problems occur when there is unwanted resistance in the circuit. The higher-than-normal resistance causes the current flow to be lower than normal and the components in the circuit are

LEFT DOOR CONNECTOR AND WINDOW LIFT SWITCH FUNCTION			
B+ POLARITY	B- POLARITY	SWITCH SECTION	WINDOW MOVEMENT
WT	LB	4	LEFT FRONT UP
LB	WT	4	LEFT FRONT DOWN
VT/WT*	BR/WT*	3	RIGHT FRONT UP
BR/WT*	VT/WT*	3	RIGHT FRONT DOWN
RD/BK*	DB/WT*	2	LEFT REAR UP
DB/WT*	RD/BK*	2	LEFT REAR DOWN
DG/WT*	GY/BK*	1	RIGHT REAR UP
GY/BK*	DG/WT*	1	RIGHT REAR DOWN
—	BK	N/A	GROUND B-
TN	—	5	GROUND B+



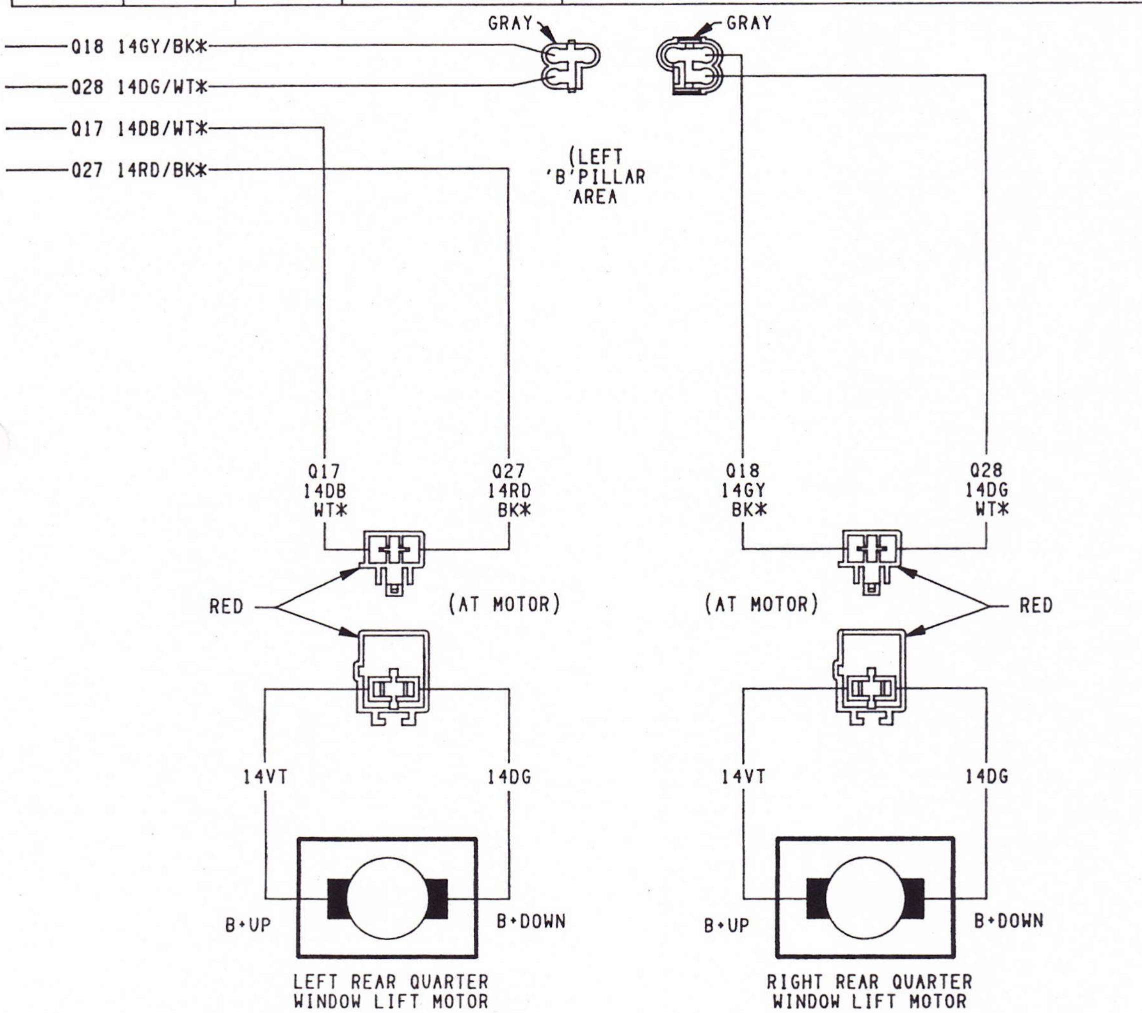


FIGURE 14–50 *Continued*

unable to operate properly. A common cause of this type of problem is corrosion at a connector. The corrosion becomes an additional load in the circuit. This load uses some of the circuit's voltage, which prevents full voltage to the normal loads in the circuit.

With a basic understanding of electricity and simple circuits, it is easier to understand the operation and purpose of the various types of electrical test equipment described in the following sections.

Electrical Test Meters

Several meters are used to test and diagnose electrical systems. These are the voltmeter, ammeter, and ohmmeter. These should be used along with volt-

PREFIX	SYMBOL	RELATION TO BASIC UNIT
Mega	M	1,000,000
Kilo	k	1,000
Milli	m	.001 or $\frac{1}{1000}$
Micro	µ	.000001 or $\frac{1}{1000000}$
Nano	n	0.000000001
Pico	p	0.000000000001

FIGURE 14–51 Common prefixes used on meters.

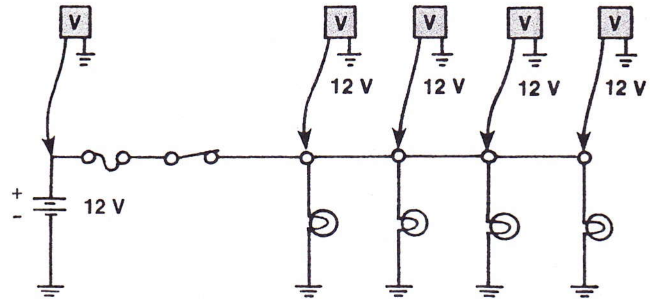


FIGURE 14–52 Checking a circuit using a voltmeter.

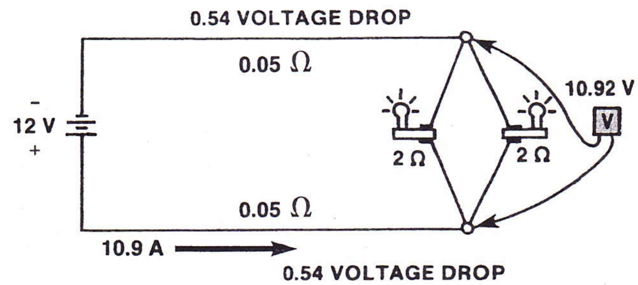


FIGURE 14–53 Wire resistance results in a slight voltage drop in the circuit.

ohmmeters, test lights, jumper wires, and variable resistors (piles).

Meters have either an "auto range" feature, in which the appropriate scale is automatically selected by the meter or they must be set to a particular range. In either case, you should be familiar with the ranges and the different settings available on the meter you are using. To designate particular ranges and readings, meters display a prefix before the reading or range. For example, if the meter has a setting for mAmps, this means the readings will be given in milli-amps or 1/1000th of an amp. The common prefixes, their symbols, and their meaning are shown in Figure 14–51.

Voltmeter A voltmeter measures the voltage available at any point in an electrical system. For example, it can be used to measure the voltage available at the battery. It can also be used to test the voltage available at the terminals of any component or connector. A voltmeter can also be used to test voltage drop across an electrical circuit, component, switch, or connector.

A voltmeter has two leads: a red positive lead and a black negative lead. The red lead should be connected to the positive side of the circuit or component. The black should be connected to ground or to the negative side of the component. Voltmeters should always be connected across the circuit being tested.

Consider a simple circuit (Figure 14–52). If there are 12 volts available at the battery and the switch is closed, there should also be 12 volts available at each light. If, for example, less than 12 volts is indicated, that would mean that some additional resistance is somewhere else in the circuit. The lights may light but not as brightly as they should.

The loss of voltage due to resistance in wires, connectors, and loads is called voltage drop. Voltage drop is checked using a voltmeter. The procedure for checking voltage is shown in Photo Sequence 7.

Figure 14–53 illustrates two headlights connected to a 12-volt battery using two wires. Each wire has a resistance of 0.05 ohm. Each headlight has a resistance of 2 ohms. As you can see, the two headlights are wired parallel so their effective resistance is

$$\frac{2\text{ ohms} \times 2\text{ ohms}}{2\text{ ohms} + 2\text{ ohms}} = 1\text{ ohm}$$

The total circuit resistance is

$$1\text{ ohm} + 0.05\text{ ohm} + 0.05\text{ ohm} = 1.1\text{ ohms}$$

Therefore, the current in the circuit is

$$I = \frac{E}{R} = \frac{12}{1.1} = 10.9\text{ amperes}$$

The voltage drop across each wire is

$$E = I \times R$$
$$E = 10.9 \times 0.05 = 0.54\text{ V}$$

This means there is a total of 1.08 volts dropped across the wires. When the voltage drop of the wires is subtracted from the 12-volt source voltage, 10.92 volts remain for the headlights.

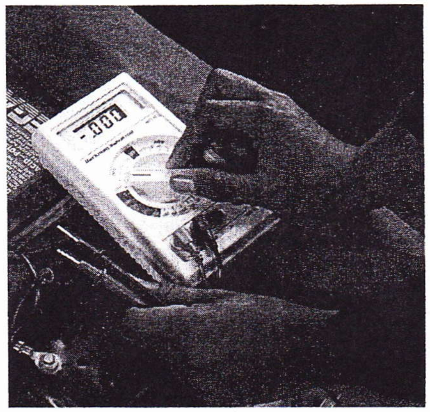
Without the resistance in the wires, the headlights receive 12 amperes. With the resistance, the current flow was reduced to 10.9 amperes.

All wiring must have resistance values low enough to allow enough voltage to the load for prop-

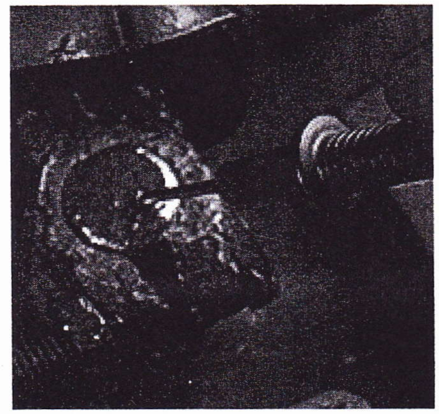
PHOTO SEQUENCE 7

PERFORMING A VOLTAGE DROP TEST

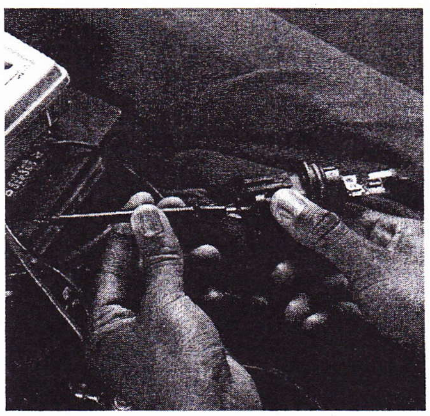
P7–1 Tools required to perform this task: voltmeter and fender covers.



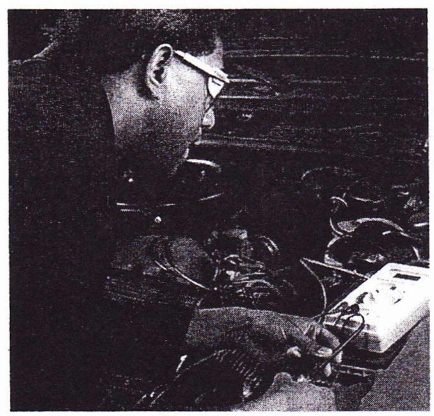
P7–2 Set the voltmeter on its lowest DC volt scale.



P7–3 To test the voltage drop of the entire headlamp system, connect the positive (red) lead to the battery positive (+) terminal.



P7–4 Connect the negative (black) lead to the low beam terminal of the headlight socket. Make sure you are connected to the input side of the headlight.



P7–5 Turn on the headlights (low beam) and look at the voltmeter reading. The voltmeter will show the amount of voltage dropped between the battery and the headlight. This reading should be very low

er operation. The maximum allowable voltage loss due to voltage drops across wires, connectors, and other conductors in an automotive circuit is 10 percent of the system voltage. So, in an automotive electrical system powered by a 12-volt battery, this maximum loss is 1.2 volts.

A voltmeter can also be used to check for proper circuit grounding. For example, consider the lighting circuit shown in Figure 14–52. If the voltmeter reading indicates full voltage at the lights, but no lighting is seen, the bulbs or sockets could be bad or the ground connection is faulty.

An easy way to check for a defective bulb is to replace it with one known to be good. You can also use an ohmmeter to check for electrical continuity through the bulb.

If the bulbs are not defective, the problem lies in either the light sockets or ground wires. Connect the voltmeter to the ground wire and a good ground as shown in Figure 14–54. If the light socket is defec-

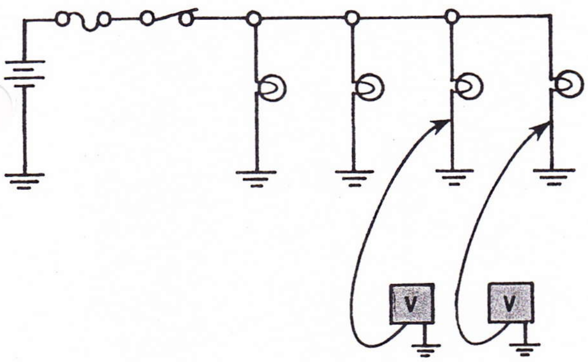


FIGURE 14–54 Using a voltmeter to check for open grounds.

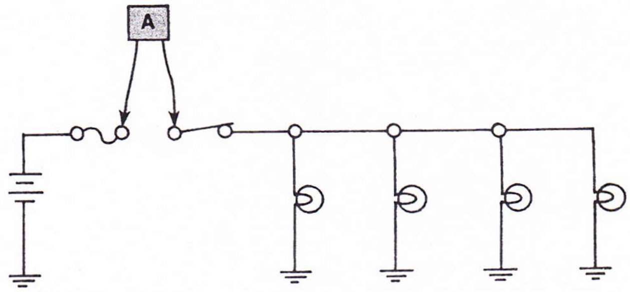


FIGURE 14–55 Checking a circuit using an ammeter.

tive, there would be no voltage through the lights and the voltmeter would read 0 volts. If the socket was not defective but the ground wire was broken or disconnected, the voltmeter would read very close to 12 volts. Any voltage reading would indicate a bad or poor ground circuit. The higher the voltage, the greater the problem.

Ammeter An ammeter measures current flow in a circuit. Current is measured in amperes. An ammeter must be placed into the circuit or in series with the circuit being tested. Normally, this requires disconnecting a wire or connector from a component and connecting the ammeter between the wire or connector and the component. The red lead of the ammeter should always be connected to the side of the connector closest to the positive side of the battery and the black lead should be connected to the other side.

WARNING!

Never place the leads of an ammeter across the battery or a load. This puts the meter in parallel with the circuit and will blow the fuse in the ammeter or possibly destroy the meter. ■

It is much easier to test current using an ammeter with an inductive pickup. The pickup clamps around the wire or cable being tested. The ammeter determines amperage based on the magnetic field created by the current flowing through the wire. This type of pickup eliminates the need to separate the circuit to insert the meter.

Because ammeters are built in very low internal resistance, connecting them in series does not add any appreciable resistance to the circuit. Therefore, an accurate measurement of the current flow can be taken.

For example, assume that a circuit normally draws 5 amps and is protected by a 6-amp fuse. If the circuit constantly blows the 6-amp fuse, a short exists somewhere in the circuit (Figure 14–55). Mathematically, each light should draw 1.25 amperes ($5 \div 4 = 1.25$). To find the short, disconnect all lights by removing them from their sockets. Then, close the switch and read the ammeter. With the load disconnected, the meter should read 0 amperes. If there is any reading, the wire between the fuse block and the socket is shorted to ground.

If zero amps was measured, reconnect each light in sequence. The reading should increase 1.25 amperes with each bulb. If, when making any connection, the reading is higher than expected, the problem is in that part of the light circuit.

WARNING!

When testing for a short, always use a fuse. Never bypass the fuse with a wire. The fuse should be rated at no more than 50 percent higher capacity than specifications. This offers circuit protection and provides enough amperage for testing. After the problem is found and corrected, be sure to install the specified rating of fuse for circuit protection. ■

Ohmmeter An ohmmeter measures resistance to current flow in a circuit. The two leads of the ohmmeter are placed across or in parallel with the circuit or component being tested. The red lead is placed on the positive side of the circuit, and the black lead is placed on the negative side of the circuit. The meter sends current through the component and determines the amount of resistance based on the voltage dropped across the load. The scale of an ohmmeter reads from 0 to infinity (∞). A 0 reading means there is no resistance in the circuit and may indicate a short in a component that should show a specific resistance. An infinity reading indicates a number higher than the meter can measure. This usually is an indication of an open circuit.

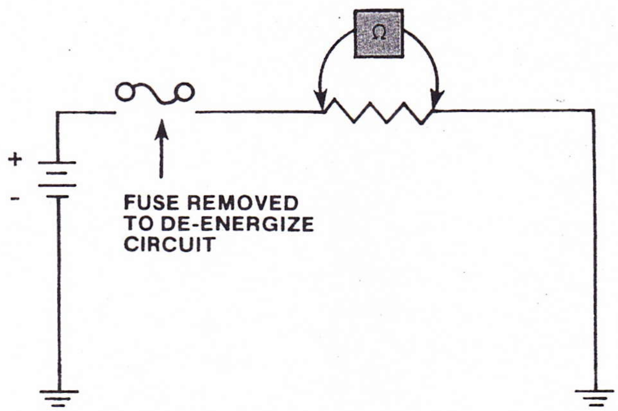


FIGURE 14–56 Measuring resistance using an ohmmeter. Note that the circuit fuse is removed to de-energize the circuit.

Ohmmeters are used to test circuit continuity and resistance with no power applied. In other words, the circuit or component to be tested must first be disconnected from the power source (Figure 14–56). Connecting an ohmmeter into a live circuit usually results in damage to the meter.

Ohmmeters are also used to trace and check wires or cables. Assume that one wire of a four-wire cable is to be found. Connect one probe of the ohmmeter to the known wire at one end of the cable and touch the other probe to each wire at the other end of the cable. Any evidence of resistance, such as meter needle deflection, indicates the correct wire. Using this same method, you can check a suspected defective wire. If resistance is shown on the meter, the wire is sound. If no resistance is measured, the wire is defective (open). If the wire is okay, continue checking by connecting the probe to other leads. Any indication of resistance indicates that the wire is shorted to one of the other wires and that the harness is defective.

Volt-Ohmmeter This combination meter is very useful for all types of diagnostics. It is capable of measuring exact amounts of voltage and resistance at any point in a circuit. Basically, there are two types of volt-ohmmeters available: the analog and digital. Analog meters use a sweeping needle to indicate the measurement. This type of meter is commonly used on normal automotive electrical circuits. A digital volt-ohmmeter (DVOM) is used on electronic circuitry. This type meter displays the measurement in numerical or digital form. Most DVOMs are of high impedance, which is a requirement for use on most computerized and other sensitive electronic equipment.

Testlights There are two types of testlights commonly used in diagnosing electrical problems, the nonpowered and powered testlight. Nonpowered testlights are used to check for available voltage. With the wire lead connected to ground and the tester's probe at a point of voltage, the light turns on with the presence of voltage (Figure 14–57A). The amount of voltage determines the brightness of the light. A self-powered testlight is used to check for continuity. Hooked across a circuit or component, the light turns on if the circuit is complete. A powered testlight should only be used if the power for the circuit or component has been disconnected (Figure 14–57B).

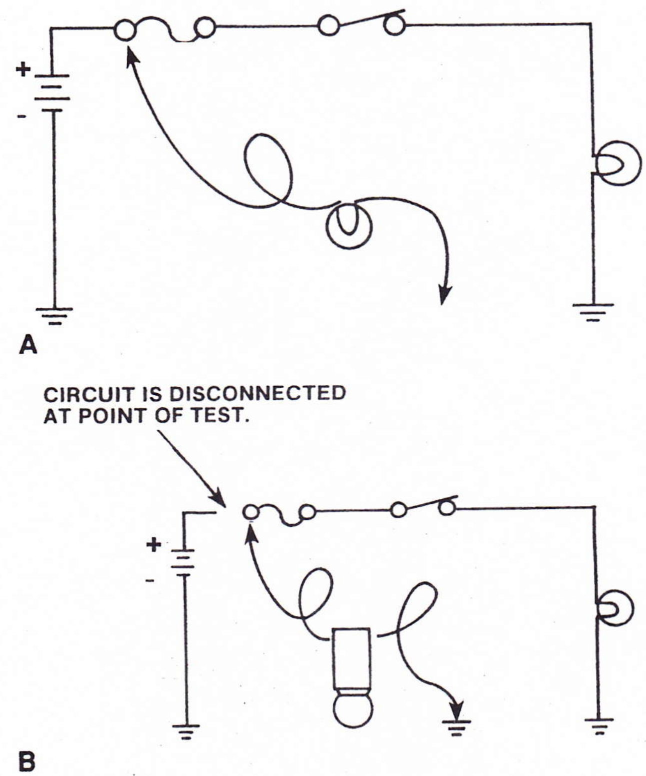


FIGURE 14–57 (A) Testing a circuit using a nonpowered test light, and (B) testing with a powered test light. With powered test lights, the circuit must be de-energized.

Jumper Wires Jumper wires are used to bypass individual wires, connectors, or components. Bypassing a component or wire helps to determine if that part is faulty (Figure 14–58). If the problem is no longer evident after the jumper wire is installed, the part by-

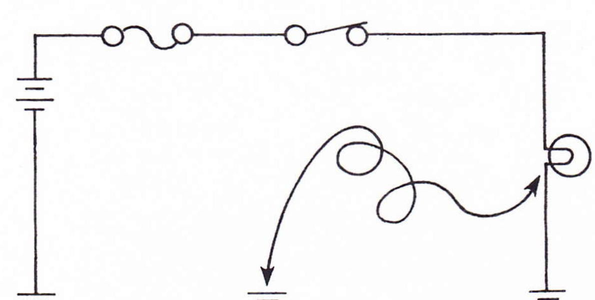


FIGURE 14–58 Using a jumper wire to test for an open ground.

passed is normally faulty. Technicians typically have jumper wires of various lengths, usually some of the wires have a fuse or circuit breaker in them to protect the circuits being tested.

Variable Resistors Variable resistors or piles are used to cause a certain amount of current to flow through a circuit. This type of test equipment is especially important when testing a battery and alternator. By causing current flow through the test equipment, the ability of the battery or alternator to react to the current draw is a precise way to check its efficiency. Most battery/starting/charging system testers are equipped with a carbon pile. The resistance of the carbon pile is either adjusted by the technician or is automatically adjusted by the tester.

Troubleshooting Circuits

Troubleshooting electrical problems involves using meters, testlights, and jumper wires to determine if any part of the circuit is open or shorted, or if there is unwanted resistance.

To troubleshoot a problem, always begin by verifying the customer's complaint. Operate the system and others to get a complete understanding of the problem. Often there are other problems that are not is evident or bothersome to the customer that will provide helpful information for diagnostics. Obtain the correct wiring diagram for the car and study the circuit that is affected. From the diagram, you should be able to identify testing points and probable problem areas. Test and use logic to identify the cause of the problem.

An ammeter and a voltmeter connected to a circuit at the different locations shown in Figure 14–59 should give readings as indicated when there are no problems in the circuit.

If there is an open anywhere in the circuit, the ammeter will read zero currents. If the open is in the 1-ohm resistor, a voltmeter connected from C to ground will read zero. However, if the resistor is open

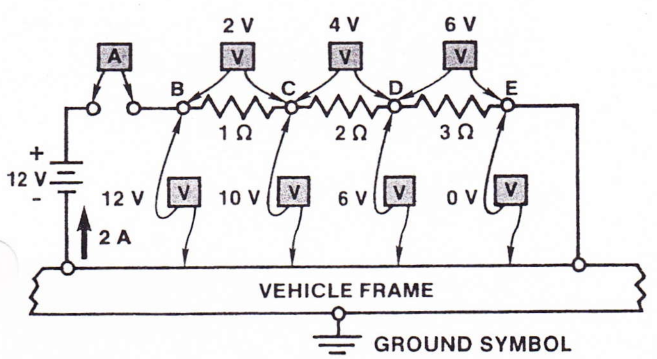


FIGURE 14–59 Sample circuit being tested with voltmeter and ammeter.

and the voltmeter is connected to points B and C, the reading will be 12 volts. The reason is that the battery, ammeter, voltmeter, 2-ohm resistor, and 3-ohm resistor are all connected together to form a series circuit. Because of the open in the circuit, there is only current flow in the circuit through the meter, not the rest of the circuit. This current flow is very low because the meter has such high resistance. Therefore, the voltmeter will show a reading of 12 volts, indicating little, if any, voltage drop across the resistors.

To help you understand this concept, look at what happens if the 2-ohm resistor was open instead of the 1-ohm resistor. A voltmeter connected from point C to ground would indicate 12 volts. The 1-ohm resistor in series in the high resistance of the voltmeter would have little affect on the circuit. If an open should occur between point E and ground, a voltmeter connected from points B, C, D, or E to ground would read 12 volts. A voltmeter connected across any one of the resistors, from B to C, C to D, or D to E, would also read zero volts, because there will be no voltage drops if there is no current flow.

A short would be indicated by excessive current and/or abnormal voltage drops. These examples illustrate how a voltmeter and ammeter may be used to check for problems in a circuit. An ohmmeter also may be used to measure the values of each component and compared to specifications. If there is no continuity across a part, it is open. If there is more resistance than called for, there is high internal resistance. If there is less resistance than specified, the part is shorted.

Repairing Connecting and Wiring Many automotive electrical problems can be traced to faulty wiring. Loose or corroded terminals, frayed, broken, or oil-soaked wires, and faulty insulation are the most common causes. Wires, fuses, and connections should be checked carefully during troubleshooting. Keep in mind that the insulation does not always appear to be damaged when the wire inside is broken. Also, a terminal may be tight but still may be corroded.

Wire end terminals are connecting devices. They are generally made of tin-plated copper and come in many shapes and sizes. They may be either soldered or crimped in place.

When installing a terminal, select the appropriate size and type terminal. Be sure it is suitable for the unit connecting post or prongs and it has enough current carrying capacity for the circuit. Also, make sure it is heavy enough to endure normal wire flexing and vibration. Ring terminals should be used for critical applications or where heavy vibration occurs. Because they completely encircle the post, they will

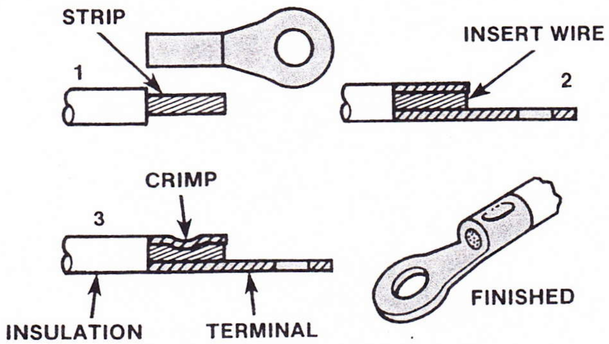


FIGURE 14–60 Proper method of crimping a wire to a terminal.

not fall off if the connection loosens. Figure 14–60 shows how to crimp a terminal. Be sure to use the proper crimping tool and to follow the tool manufacturer's instructions.

WARNING!

Do not crimp a terminal with the cutting edge of a pair of pliers. While this method may crimp the terminal, it also weakens it. ■

General procedures for crimping on a connector follows:

1. Use the correct size stripping opening on the crimping tool (Figure 14–61) and remove enough insulation to allow the wire to completely penetrate the connector.
2. Place the wire into the connector and crimp the connector (Figure 14–62). To get a proper crimp, place the open area of the connector facing toward the anvil. Make sure the wire is compressed under the crimp.
3. Insert the stripped end of the other wire into the connector, if connecting two wires, and crimp in the same manner.
4. Use electrical tape or heat shrink tubing to tightly seal the connection. This will provide good protection for the wire and connector.

The preferred way to connect wires or to install a connector is by soldering. Photo Sequence 8 demonstrates the proper procedure for soldering two copper wires together. Some car manufacturers use aluminum in their wiring. Aluminum cannot be soldered. Follow the manufacturer's guidelines and use the proper repair kits when repairing aluminum wiring.

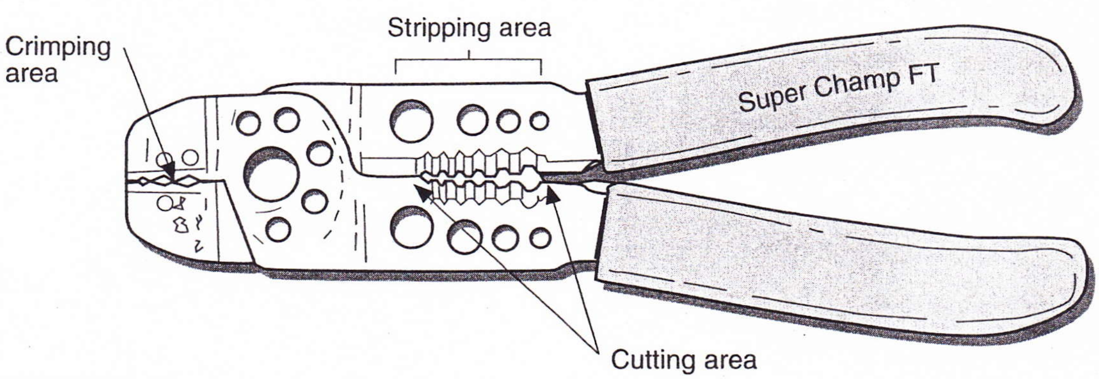


FIGURE 14–61 Typical crimping tool used for making electrical repairs.

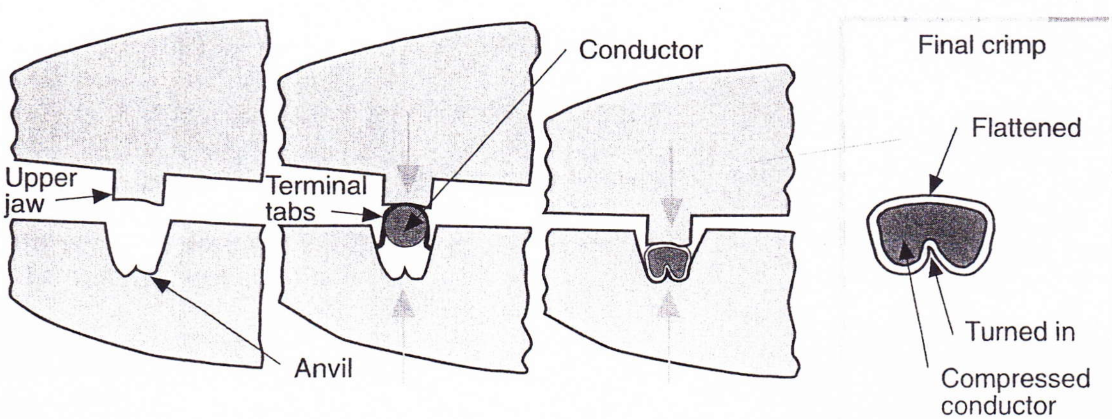
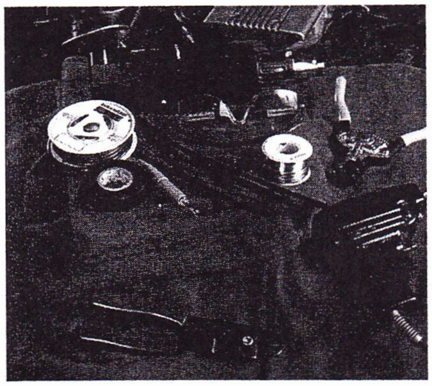


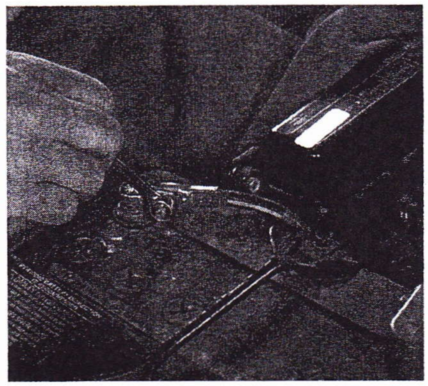
FIGURE 14–62 Crimping the connector properly.

PHOTO SEQUENCE 8

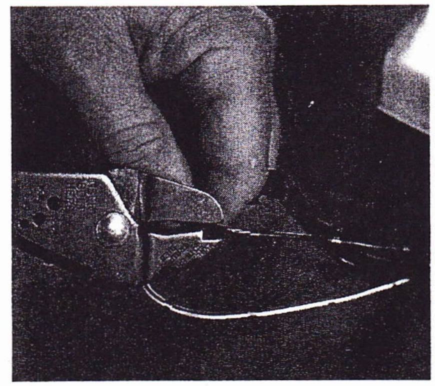
SOLDERING TWO COPPER WIRES TOGETHER



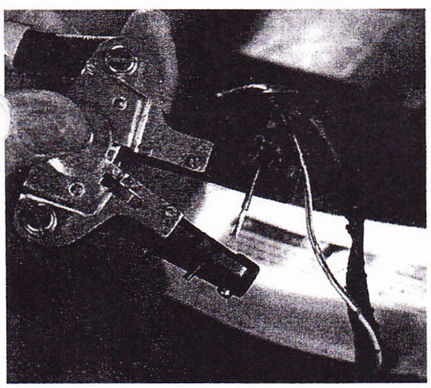
P8–1 Tools required to solder copper wire: 100-watt soldering iron, 60/40 rosin core solder, crimping tool, splice clip, heat shrink tube, heating gun, and safety glasses.



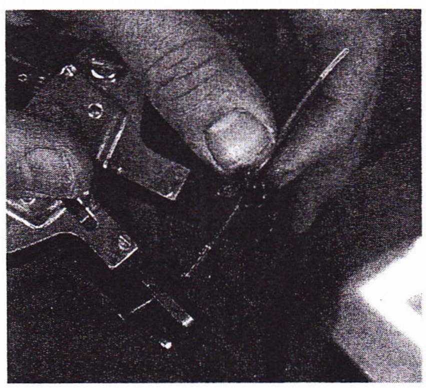
P8–2 Disconnect the fuse that powers the circuit being repaired. Note: If the circuit is not protected by a fuse, disconnect the ground lead of the battery.



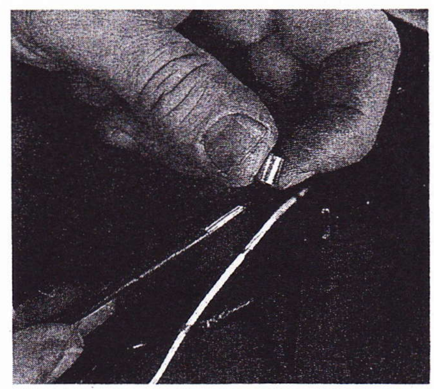
P8–3 Cut out the damaged wire.



P8–4 Using the correct size stripper, remove about 1/2 inch of the insulation from both wires.



P8–5 Now remove about 1/2 inch of the insulation from both ends of the replacement wire. The length of the replacement wire should be slightly longer than the length of the wire removed.



P8–6 Select the proper size splice clip to hold the splice.

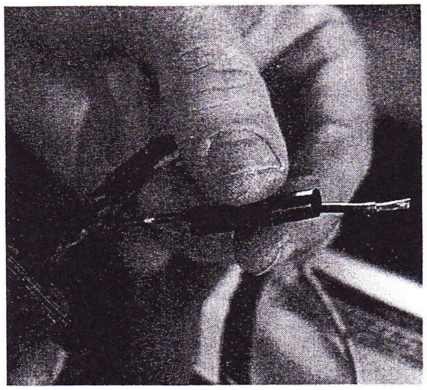
WARNING!

Never use acid core solder. It creates corrosion and can damage electronic components. ■

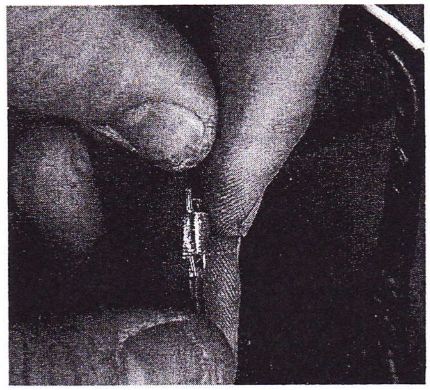
When working with wiring and connectors, never pull on the wires to separate the connectors. This can create an intermittent contact and an intermittent problem that may be very difficult to find later. When required, always use the special tools designed for separating connectors.

Never reroute wires when making repairs. Rerouting wires can result in induced voltages in nearby components. These stray voltages can interfere with the function of electronic circuits.

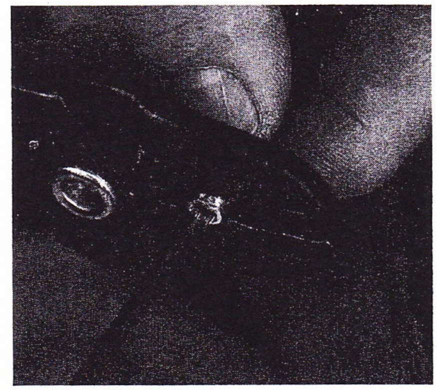
Dielectric grease is used to moistureproof and protect connections from corrosion. Some car manufacturers suggest using petroleum jelly to protect connection points.



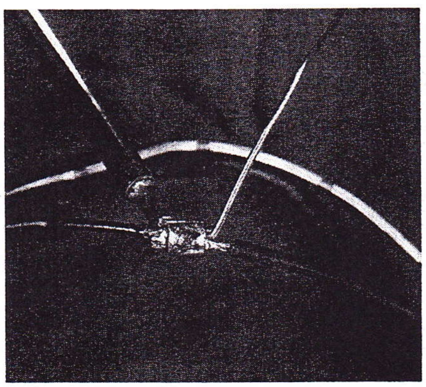
P8–7 Place the correct size and length of heat shrink tube over the two ends of the wire.



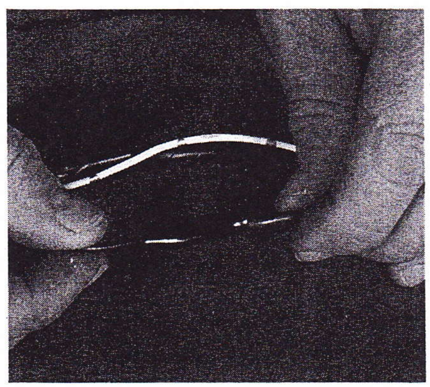
P8–8 Overlap the two splice ends and center the splice clip around the wires, making sure the wires extend beyond the splice clip in both directions.



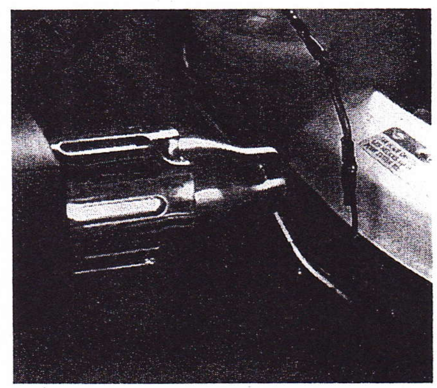
P8–9 Crimp the splice clip firmly in place.



P8–10 Heat the splice clip with the soldering iron while applying solder to the opening of the clip. Do not apply solder to the iron. The iron should be 180 degrees away from the opening of the clip.



P8–11 After the solder cools, slide the heat shrink tube over the splice.



P8–12 Heat the tube with the hot air gun until it shrinks around the splice. Do not overheat the heat shrink tube

ELECTROMAGNETISM BASICS

Electricity and magnetism are related. One can be used to create the other. Current flowing through a wire creates a magnetic field around the wire. Moving a wire through a magnetic field creates current flow in the wire.

Many automotive components, such as alternators, ignition coils, starter solenoids, and magnetic pulse generators operate using these principles of **electromagnetism**.

Fundamentals of Magnetism

A substance is said to be a **magnet** if it has the property of magnetism—the ability to attract such substances as iron, steel, nickel, or cobalt. These are called magnetic materials.

A magnet has two points of maximum attraction, one at each end of the magnet. These points are called **poles**, with one being designated the North pole and the other the South pole (Figure 14–63A). When two magnets are brought together, opposite poles attract (Figure 14–63B), while similar poles repel each other (Figure 14–63C).

A magnetic field, called a **flux field** (Figure 14–64), exists around every magnet. The field consists of imaginary lines along which the magnetic force acts. These lines emerge from the North pole and enter the South pole, returning to the North pole

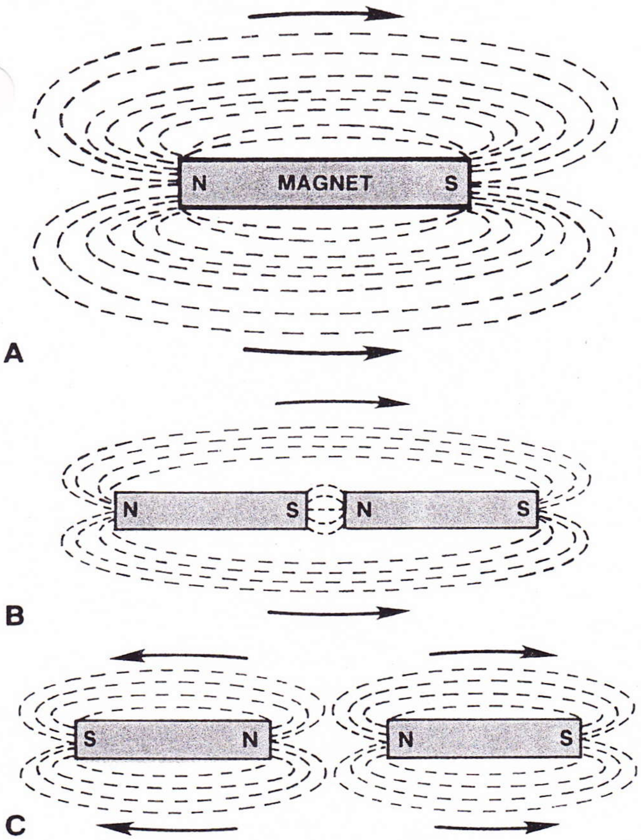


FIGURE 14–63 (A) In a magnet, lines of force emerge from the North pole and travel to the South pole before passing through the magnet back to the North pole. (B) Unlike poles attract, while (C) similar poles repel each other.

through the magnet itself. All lines of force leave the magnet at right angles to the magnet. None of the lines cross each other. All lines are complete.

Magnets can occur naturally in the form of a mineral called magnetite. Artificial magnets can also be made by inserting a bar of magnetic material inside a coil of insulated wire and passing direct current through the coil. This principle is very important in understanding certain automotive electrical components. Another way of creating a magnet is by stroking the magnetic material with a bar magnet. Both methods force the randomly arranged molecules of the magnetic material to align themselves along North and South poles (Figure 14–65).

Artificial magnets can be either temporary or permanent. Temporary magnets are usually made of soft iron. They are easy to magnetize but quickly lose their magnetism when the magnetizing force is removed. Permanent magnets are difficult to magnetize. However, once magnetized they retain this property for very long periods.

The earth is a very large magnet, having a North and South pole, with lines of magnetic force running between them. This is why a compass always aligns itself to straight north and south.

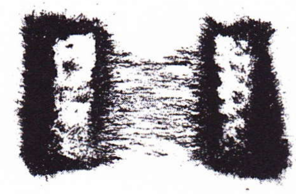


FIGURE 14–64 Iron filings show the lines of magnetic flux.

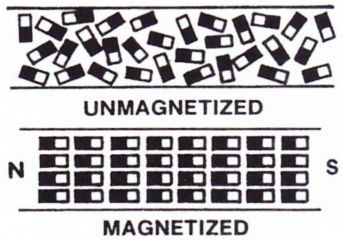


FIGURE 14–65 Molecular arrangement of unmagnetized and magnetized iron.

In 1820, a simple experiment discovered the existence of a magnetic field around a current-carrying wire. When a compass was held over the wire, its needle aligned itself at right angles to the wire (Figure 14–66). The lines of magnetic force are concentric circles around the wire. The density of these circular lines of force is very heavy near the wire and decreases farther away from the wire. As is also shown in the same figure, the polarity of a current-carrying wire's magnetic field changes depending on the direction the current is flowing through the wire.

Remember, these magnetic lines of force or flux lines do not move or flow around the wire. They simply have a direction as shown by their effect on a compass needle. These lines of force are always at right angles to the conducting wire.

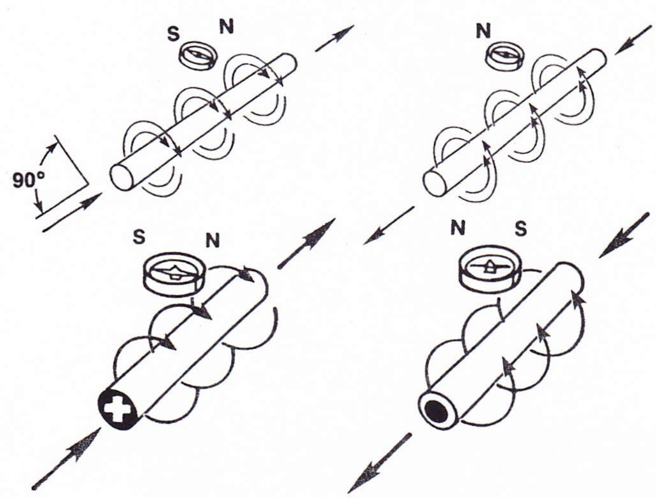


FIGURE 14–66 When current is passed through a conductor such as wire, magnetic lines of force are generated around the wire at right angles to the direction of the current flow.

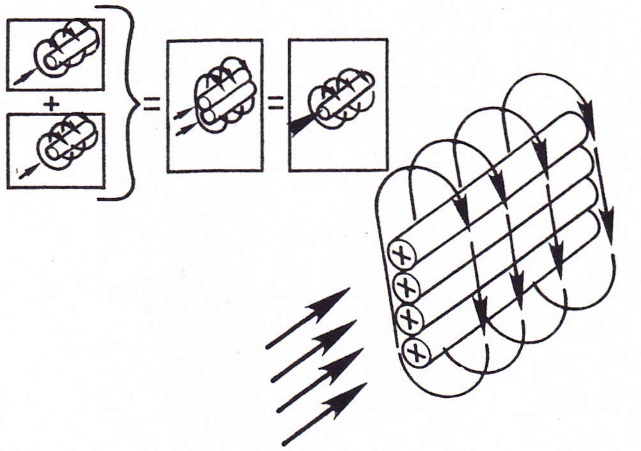


FIGURE 14–67 Increasing the number of conductors carrying current in the same direction increases the strength of the magnetic field around them.

FLUX DENSITY The more flux lines, the stronger the magnetic field at that point. Increasing current will increase **flux density**. Also, two conducting wires lying side by side carrying equal currents in the same direction create a magnetic field equal in strength to one conductor carrying twice the current. Adding more wires also increases the magnetic field (Figure 14–67).

COILS Looping a wire into a coil concentrates the lines of force inside the coil. The resulting magnetic field is the sum of all the single-loop magnetic fields added together (Figure 14–68). The overall effect is the same as placing many wires side by side, each carrying current in the same direction.

Magnetic Circuits and Reluctance

Just as current can only flow through a complete circuit, the lines of flux created by a magnet can only occupy a closed magnetic circuit. The resistance that a magnetic circuit offers to a line of flux is called **reluctance**. Magnetic reluctance can be compared to electrical resistance.

Reconsider the coil of wire shown in Figure 14–68. The air inside the coil has very high reluctance and limits the magnetic strength produced. However, if an iron core is placed inside the coil, magnetic strength increases tremendously. This is because the iron core has a very low reluctance (Figure 14–69).

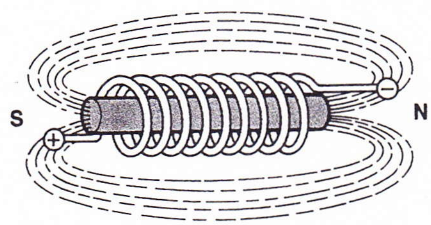


FIGURE 14–69 Placing a soft iron core inside a coil greatly reduces the reluctance of the coil and creates a usable electromagnet.

When a coil is wound around an iron core in this manner, it becomes a usable electromagnet. The strength of the magnetic poles in an electromagnet is directly proportional to the number of turns of wire and the current flowing through them.

The equation for an electromagnetic circuit is similar to Ohm's law for electrical circuits. It states that the number of magnetic lines is proportional to the ampere-turns divided by the reluctance. To summarize:

- Field strength increases if current through the coil increases.
- Field strength increases if the number of coil turns increases.
- If reluctance increases, field strength decreases.

Induced Voltage

Now that we have explained how current can be used to generate a magnetic field, it is time to examine the opposite effect of how magnetic fields can produce electricity.

Figure 14–70 shows a straight piece of wire with the terminals of a voltmeter attached to both ends. If the wire is moved across a magnetic field, the voltmeter registers a small voltage reading. A voltage has been induced in the wire.

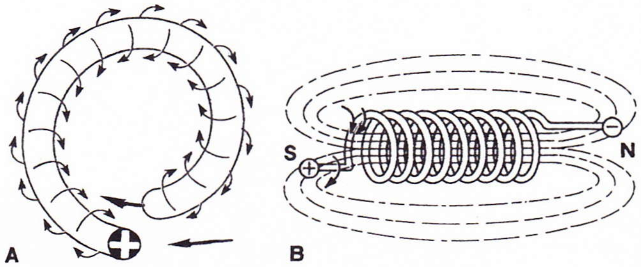


FIGURE 14–68 (A) Forming a wire loop concentrates the lines of force inside the loop. (B) The magnetic field of a wire coil is the sum of all the single-loop magnetic fields.

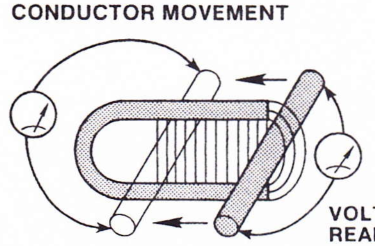


FIGURE 14–70 Moving a conductor so it cuts across the magnetic lines of force induces a voltage in the conductor.

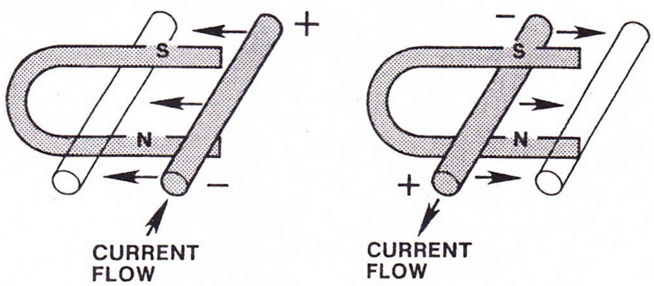


FIGURE 14–71 The polarity of the induced voltage depends on the direction in which the conductor moves as it cuts across the magnetic field.

It is important to realize that the wire must cut across the flux lines to induce a voltage. Moving the wire parallel to the lines of flux does not induce voltage.

Voltage can also be induced by holding the wire still and moving the magnetic field at right angles to the wire. This is the exact setup used in a vehicle's alternator. A magnetic field is made to cut across stationary conductors to produce voltage.

The wire becomes a source of electricity and has a polarity or distinct positive and negative end. However, this polarity can be switched depending on the relative direction of movement between the wire and magnetic field (Figure 14–71). This is why charging devices produce alternating current.

The amount of voltage that is induced depends on four factors.

- The stronger the magnetic field, the stronger the induced voltage.
- The faster the field is being cut, the more lines of flux are cut and the stronger the voltage induced.
- The greater the number of conductors, the greater the voltage induced.
- The closer the conductor(s) and magnetic field are to right angles (perpendicular) to one another, the greater the induced voltage.

The importance of electromagnetism and induced voltage is clearly seen in chapters dealing with starting, charging, ignition, and electronic control systems.

KEY TERMS

AWG
Blade fuse
Capacitor
Cartridge fuse
Ceramic fuse
Circuit breaker
Closed circuit
Conductor
Continuity
Dielectric
Electromagnetism
Fixed value resistors
Flux density
Flux field
Fusible link
Ganged
Ground wire
Grounding
High-tension cable
In-line fuse
Insulator
Magnet
Maxi-fuse
MPMT
Normally closed
Normally open
Ohm's law
Open circuit
Parallel circuit
Poles
Potentiometer
Relay
Reluctance
Resistor wire
Rheostat
Schematic
Sensor
Series circuit
Series-parallel circuit
Solenoid
Solid wire
Spade fuse
SPDT
SPST
Stepped resistor
Stranded wire
Tapped resistor
Thermistor
Throw
Trimmer
Variable resistor
Voltage drop
Voltage limiter

SUMMARY

- For electrical flow to occur there must be an excess of electrons in one place, a lack of electrons in another, and a path between the two places.
- Voltage is the force or pressure in an electrical circuit. A voltage drop across a load in a circuit indicates that work is being done.
- Current is measured in amps. This is a measurement of the actual flow rate of electrons in an electrical circuit.
- Resistance is measured in ohms. This is a measurement of the size of the restriction to current flow. The more resistance there is, the less current will be able flow through the circuit.
- The mathematical relationship between current, resistance, and voltage is expressed in Ohm's law, $E = IR$, where voltage is measured in volts, current in amperes, and resistance in ohms.
- The mathematical relationship between current, voltage, and power is expressed in Watt's law, $P = E \times I$. Power is measured in watts or kilowatts (1,000 watts).
- Three basic types of circuits are used in automobile wiring systems: series circuits, parallel circuits, and series-parallel circuits.
- Electrical schematics are diagrams with electrical symbols that show the parts and how electrical current flows through the vehicle's electrical circuits. They are used in troubleshooting.
- An open circuit does not have a complete path for the current to flow through. A shorted circuit is one that allows current to flow along an unwanted path. A high-resistance problem in a circuit decreases the power available for the load.

- The strength of an electromagnet depends on the number of current-carrying conductors and what is in the core of the coil. Inducing a voltage requires a magnetic field producing lines of force, conductors that can be moved, and movement between the conductors and the magnetic field so the lines of force are cut.
- Fuses, fuse links, maxi-fuses, and circuit breakers protect circuits against overloads. Switches control on/off and direct current flow in a circuit. A relay is an electric switch. A solenoid is an electromagnetic switch that translates current flow into mechanical movement. Resistors limit current flow.

TECH MANUAL

The following procedures are included in Chapter 14 of the *Tech Manual* that accompanies this book:

1. Check continuity in a circuit with a test light.
2. Check applied voltages with a voltmeter.
3. Check voltage drop across connectors.
4. Inspect and check fuses, fusible links, and circuit breakers.

REVIEW QUESTIONS

1. What is the name for the formula $E = I \times R$?
2. In a series circuit, resistance is always ____.
3. What kind of diagram is used to troubleshoot an electrical circuit?
4. An ammeter is always connected ____ with the circuit, while a voltmeter is connected in ____ with the circuit.
5. Variable capacitors are called ____.
6. What is the process called in which a conductor cuts across a magnetic field and produces a voltage?
7. What happens in an electrical circuit when the resistance increases?
8. What is the difference between voltage and current?
9. What kind of solder is used to repair electrical wiring?
10. What is an SPST switch?
11. For electrical flow to occur, which of the following must be present?
    a. a difference in the quantity of electrons between two places
    b. a path between two places
    c. a battery
    d. both a and b
12. Technician A says magnetism is a source of electrical energy in an automobile. Technician B says chemical reaction is a source of electrical energy in an automobile. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
13. Which of the following is *not* a circuit-protection device?
    a. a fuse
    b. a fusible link
    c. a mini-fuse
    d. a maxi-fuse
14. Technician A uses a test light to detect resistance. Technician B uses a jumper wire to test circuit breakers, relays, and lights. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
15. Which type of resistor is commonly used in automotive circuits?
    a. fixed valve
    b. stepped
    c. variable
    d. all of the above
16. Technician A says the cross-sectional area in circular mms of a solid wire must be calculated to find its gauge. Technician B says the smaller the gauge number, the heavier the wire. Who is correct?
    a. Technician A
    b. Technician B
    c. Both A and B
    d. Neither A nor B
17. What is the current in a 12-volt circuit with two 6-ohm resistors connected in parallel?
    a. 2 amps
    b. 4 amps
    c. 6 amps
    d. 12 amps

18. While discussing a 12-volt circuit with three resistors (a 3-ohm, a 6-ohm, and a 2-ohm) in parallel: Technician A says the total resistance of the circuit is 1 ohm. Technician B says the current flow through the 6-ohm resistor is 12-amps. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B

19. Which of the following statements is untrue?

a. A short causes increased current flow.
b. An open causes unwanted voltage drops.
c. High-resistance problems cause increased current flow.
d. Both opens and high-resistance problems may cause a load not to work.

20. Technician A says a 12-volt light bulb that draws 12 amps has a power output of 1 watt. Technician B says a motor that has 1 ohm of resistance has a power rating of 144 watts if it is connected to a 12-volt battery. Who is correct?

a. Technician A
b. Technician B
c. Both A and B
d. Neither A nor B